The green energy transition in Germany: a bibliometric study

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Abstract

The global energy landscape is undergoing a significant shift toward green energy solutions, with Germany leading the way in the transition to renewable energy through its Energiewende initiative. This topic is of great importance as it offers valuable insights for other countries in the European Union and worldwide seeking sustainable and environmentally friendly alternatives for their energy sectors.

This paper aims to provide a comprehensive assessment of Germany's green energy transition, focusing on the technological advancements, strategic management, and country economics that drive this transformation.

Utilising a bibliometric study research method, the paper analyses data from scientific publications in the Scopus database and employs VOSviewer and Bibliometrix software to develops bibliometric maps of keyword co-occurrences.

The analysis reveals the main changes in Germany's green energy transition, uncovering the meaning and important structures of keywords, suggesting new directions for research, and pointing out strategies based on the technological transition toward renewable energy sources and green job creation.

By integrating sustainable development and technological changes, this study contributes to the understanding of green energy transition strategies and their impact on adjacent domains, offering valuable insights for business and society.

Furthermore, the assessment of Germany's green energy transition serves as a valuable example for governments and policymakers in other countries, helping them to learn from Germany's experience and implement similar strategies in their energy sectors. The full paper will discuss the limitations of the paper and potential directions for future research.

Key words

bibliometric analysis, energy sector transformation, VOSviewer.

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Introduction

The energy sector is the foundation of all economies and impacts all other sectors (Yang, 2022; Zema and Sulich, 2022). Even though Germany is one of the largest carbon emitters in the European Union, it is the leader in redirecting the process of electricity generation towards renewable energy (Schumacher and Sands, 2006). There are multiple reports and scientific papers describing this contradiction (Feder, 2022; Ringel, 2018); however, little has been explained about the technological change supported by strategic management (Sulich and Grudziński, 2019; Švarova and Vrchota, 2013). This transition, called *Energiewende* in German (Feder, 2022), has enabled Germany to transition from fossil fuels to clean and nuclear energy, and then implement more renewable energy resources in its energy mix (Grzesiak and Sulich, 2022; Li, 2021). Collectively, scientific journals have published an extensive range of contributions to the green energy transition (Moskalenko et al., 2022), including management research (Shpak et al., 2021) and technical-based research (Maruf, 2021) describing the German *Energiewende*.

The cost of energy generation is a key factor that plays into the health of German industry and the economy (Rubin et al., 2007; Yang, 2022). The transition to net zero emissions by 2045 requires significant investment and a clear understanding of the options available for generating electricity, as well as an energy mix that provides grid stability (Shen et al., 2021). This change is also brought about by the strategic approach in the energy industry in Germany (Gajdzik et al., 2021; Gruber, 2021; Sulich and Grudziński, 2019) and a new understanding of energy security matters. As a result, renewable energy currently accounts for 32.1% of the energy generated in Germany, with wind accounting for the majority of this, or 20.3% of the total (Yang, 2022). Germany still exhibits a large reliance on fossil fuels, which contribute 55.4% of its energy generation, with coal comprising the major share (28.1%) of its energy mix (Grzesiak and Sulich, 2022). Those data are not only visible in the publications in scientific journals, but are also part of the larger transition pattern in the German energy sector. In addition to the publications, elements of this pattern are accessible for bibliometric analysis, and the resulting networks are open to visual analysis in the form of bibliometric maps. The assessment of Germany's energy sector transition and the identification of changes in this sector of the economy are critical due to the country's reliance on depleting resources in other countries (Wettengel, 2023). The direct implications of the green energy transition in Germany are green jobs and changes in the German labour market. In Germany, the renewable energy sector creates more jobs per unit of energy than the fossil fuel-based sector (Kammen and Engel, 2009). The characteristics of the German energy sector may be an interesting example for other countries, especially European countries.

The aim of this paper is to explore secondary data gathered in the Scopus scientific database reflecting the green transition in Germany. Therefore, this paper reviews and presents the outcomes of a bibliometric analysis of scientific literature to generate a network visualisation of keyword maps (van Eck et al., 2010) and tables. The search for green energy transition in Germany was based on specified and calibrated queries with syntaxes and keyword variants employed in the exploration of scientific publications. This complex approach, which combines descriptive and analytical methods, necessitates a series of techniques in order to provide an objective assessment of Germany's green energy transition. The research method used is bibliometric analysis, which is a variation of the systematic literature review (SLR) method (Boyack et al., 2017; Zema and Sulich, 2022), with an exploration of scientific publications indexed

in the Scopus database research queries. Using Scopus and VOSviewer and Bibliometrix software, co-occurrence networks were generated to identify associations between frequently occurring keywords in scientific articles. This method provides a unique assessment of the changes observed in Germany, in terms of both the hidden and explicit aspects (Boyack et al., 2017). Understanding the process of business development and strategy transformation in the energy sector is a particularly difficult task (Jørgensen, 2005). The goal of this paper is not only to discover its underlying structure, but also to determine Germany's contribution to the emerging pattern of energy sector transformation. This paper is not purely a bibliometric analysis, because it combines three types of analytical software which are based on the quantitative approach with the qualitative interpretation of the results obtained (Gajdzik et al., 2021; Johnson-Cramer et al., 2022; Sulich and Sołoducho-Pelc, 2022).

This paper is organised as follows. After this brief introduction, the Methodology section explains the research procedure in detail along with its limitations. The detailed methodological explanation is accompanied by the presentation of the calculations and results obtained. Based on the proposed SLR variation method, the data are analysed and presented. Subsequently, in the Discussion and Conclusions subchapter, the theoretical and practical managerial implications of this study, which may be important to policymakers, businesses, researchers, and the public at large, are presented. In the last section, the limitations of the study and the possible future avenues of new research are also addressed.

1. Methodology

The method adopted in this research is the SLR variation method with queries (Bran et al., 2021; Lamers et al., 2021). In this paper, scientific literature from the Scopus database was used. The subjects of the research were scientific publications collected in the abovementioned database. The starting point of this timespan was determined by the earliest publication indexed in the Scopus scientific database; therefore, the research covered the period of 1969-2022. The Scopus database is a bibliographic database with an organised digital collection of references to published scientific literature, including journal articles, conference proceedings, patents, books etc. (Elsevier, 2023; Zema and Sulich, 2022). In general, scientific databases contain highly detailed subject descriptions in the form of keywords, classification terms, or abstracts. Bibliographic metadata is information associated with a bibliographic record, which can be explored using visualisation tools. Scopus was chosen due to its popularity and reputation among researchers (Singh et al., 2021; Zema and Sulich, 2022).

Bibliometric keyword co-occurrence analysis has become a popular tool in management research, including business and social studies. Formal techniques for evaluating literature serve to identify influential works and track the evolution of the field (Johnson-Cramer et al., 2022). Scientometric techniques of citation analysis are based on the premise that research papers cite publications that they consider relevant. Co-occurring keywords are presented in the network as nodes in the bibliometric map. Co-occurrence analysis of keywords also highlights publications, represented as edges in the bibliometric map, indicating that they have been cited. Therefore, results presented graphically as networks uncover patterns of influence, diffusion and conceptual development of the analysed results of queries (Johnson-Cramer et al., 2022).

The SLR variation method is supported by the research queries exploring the Scopus database. The SLR has its own procedure, which is not presented in detail in this paper. In this study, the SLR method is used as a tool for the identification of knowledge gaps and future directions of research. The

SLR variation method used in this paper is based on the research queries which are used to explore the Scopus database. The results are presented in the form of bibliometric maps with the use of the VOSviewer programme (version 1.6.18). Bibliometric analysis is used in this research to produce a network visualisation of keywords for the queries (Zema and Sulich, 2022). This kind of analysis identifies and highlights clusters of keywords that have emerged in various relationships shaping the subject of Germany's green transition in the scientific literature as a whole. In this variation of the SLR method, the five original queries were formulated and developed as presented in Table 1. There are differences in the formulated queries, although the queries have a syntax that corresponds with the database in which they are used.

Table 1. Syntaxes used in queries for the exploration of the Scopus scientific database

No.	Query Syntax	No. of Results 1 Dec. 2022
1	TITLE-ABS-KEY („energy sector" AND „transition" OR „transformation") AND (LIMIT-TO (LANGUAGE, „English"))	2,159
2	(TITLE-ABS-KEY („energy sector") AND TITLE-ABS-KEY („transition" OR „transformation" AND „green")) AND (LIMIT-TO (LANGUAGE, „English"))	258
3	(TITLE-ABS-KEY („energy sector") AND TITLE-ABS-KEY („transition" OR „transformation" AND „green")) AND (LIMIT-TO (LANGUAGE, „English")) AND (LIMIT-TO (SUBJAREA, „ENER"))	145
4	((TITLE-ABS-KEY („energy sector") AND TITLE-ABS-KEY („transition" OR „transformation"))) AND („green") AND (LIMIT-TO (SUBJAREA, „ENER")) AND (LIMIT-TO (AFFILCOUNTRY, „Germany")) AND (LIMIT-TO (LANGUAGE, „English"))	73
5	(TITLE-ABS-KEY („energy sector") AND TITLE-ABS-KEY („transition" OR „transformation" AND „green")) AND (LIMIT-TO (LANGUAGE, „English")) AND (LIMIT-TO (SUBJAREA, „ENER")) AND (LIMIT-TO (AFFILCOUNTRY, „Germany"))	11

Source: own elaboration based on Scopus data

Data were collected using queries in the Scopus database. This resulted in a global dataset and facilitated the retrieval of articles based on the previously discussed search constraints (the results of the first query in Table 1) that were further segregated into smaller datasets. The query syntaxes presented in Table 1 provide a view of the research assumptions and criteria. The area of the research was set as "energy sector" by means of the direct keyword. This specified keyword searched in the TITLE-ABS-KEY fields in Scopus produced over 16,000 results. Due to the vast collection of results, the queries were calibrated and developed in Boolean style. The queries presented in Table 1 were used to study the Scopus database on 1 December 2022, with different numerical results depending on the exact syntax of each formulated query. The only constant limitation among all queries was the language of publication, when elements of other syntaxes were added. English was the most common language among the indexed publications, and was chosen accordingly. Additional keywords searched within query 1 were "transition" and "transformation", then the keyword "green" was added in query 2. In the following queries further limitations were applied, such as subject area (SUBJAREA) and affiliation country (AFFILCOUNTRY). These were

selected from the refined results sidebar on the Scopus website and the results were limited to those criteria. Queries 4 and 5 differ not only in terms of the number of results obtained but also the order of each query syntax, which was the reason behind the disproportion inherent in the results. Each time, a set of files was downloaded for the Scopus database in .csv format containing the results of queries 1 through 5 from the studied time intervals, and all publication fields were marked during export. The following fields were chosen for export from Scopus: citation information, bibliographic information, abstract, keywords, funding details, and other information (Johnson-Cramer et al., 2022; Zema and Sulich, 2022). As bibliometric software recognises only exactly matching strings of characters, a manual normalisation process is required to maintain accuracy, especially in the spelling of researched keywords. Due to generally employed bibliometric software not distinguishing between small and capital letters in the names of countries, organisations, etc., the VOSviewer programme converts the capital letters of abbreviations to lowercase. Therefore, this original form proposed by the software was maintained in the text of this study so as not to cause confusion. The distinguished keywords are consistent with the obtained bibliometric maps. This should allow readers to more readily understand which network nodes are being discussed.

The exported data were analysed in VOSviewer, and the resulting bibliometric maps display the results. The choice of the number of co-occurrences of keywords determines the graphical presentation and clarity of the bibliometric map (Waltman et al., 2013). Therefore, a minimum of five co-occurrences of keywords was established for each bibliometric map, unless another number of co-occurrences was specified for a specific map. Co-occurrence keywords serve as nodes on the bibliometric map (van Eck and Waltman, 2010). The size of the nodes, the links between the nodes, and the colour-coded clusters are three of the most important characteristics represented by network maps. Between the nodes are edges indicating the relationships between co-occurrences of keywords. Therefore, lines represent the strongest co-occurrence links between keywords. The distance between two nodes approximates the co-occurrence relationship between two keywords. The stronger the relationship between two nodes, the closer they are to each other. The bibliometric map groups items (keywords) into clusters. This means that nodes within the downloaded dataset are clustered using an algorithm programmed and applied by VOSviewer. A cluster is a subnetwork consisting of bibliometric map items. By default, VOSviewer employs a clustering algorithm to assign co-occurring keywords to clusters, which consist of nodes that are closely related. Items of greater significance are displayed more prominently on a map than those of lesser significance (Dzwigol et al., 2023; Sulich and Sołoducho-Pelc, 2022). Each network node is assigned to precisely one cluster. A resolution parameter establishes the number of clusters; the greater the value of this parameter, the greater the number of clusters. In the visualisation, VOSviewer uses colours to indicate which cluster a node belongs to. In each of the presented maps, all co-occurring keywords are coloured according to their membership in the clusters (Gajdzik et al., 2021; Sołoducho-Pelc and Sulich, 2022). The keyword co-occurrence analysis and the resulting maps provide insights into the intellectual structure of a field (Kwilinski et al., 2022). The recognition of certain patterns is possible when VOSviewer is used, because the software creates a list based on text mining of the title, abstract, and keywords in the articles within the dataset. The maps created make it possible to visualise the intellectual structure of the investigated domain. The iterative analysis was conducted using

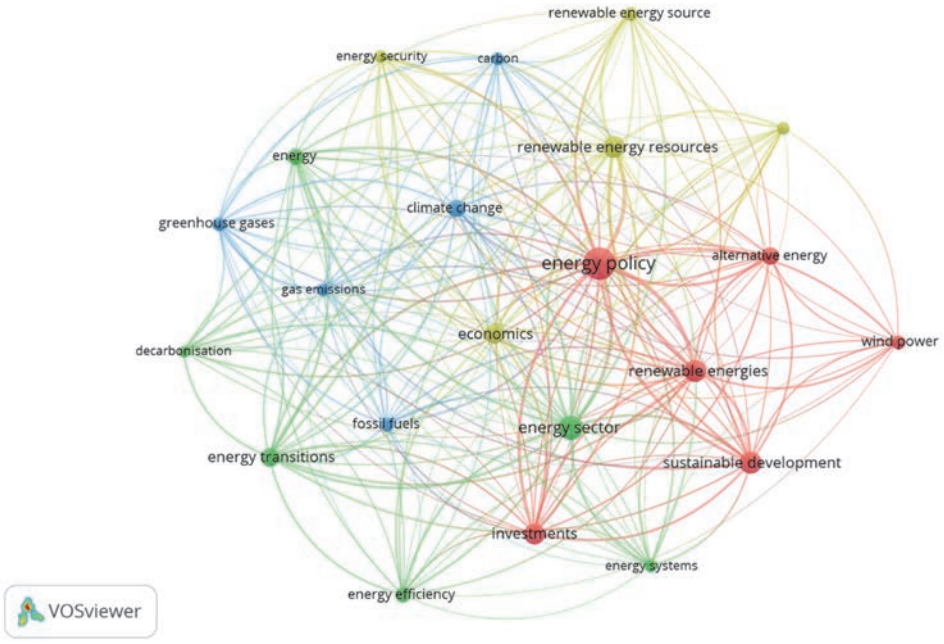
bibliometric maps and the results of the co-occurrence analysis to identify similarities, patterns, and differences. Individual observations were merged in weekly conferences to reach a consensus among those with expertise on the research topic.

The results of the third query were the subject of further analysis undertaken in Bibliometrix (version 4.1.2) in the R environment (version 4.2.1) according to the methodology proposed in the scientific literature (Aria and Cuccurullo, 2017; Martín-Cervantes and Martínez, 2022). In order to provide a comprehensive view of the green energy transition in Germany, selected analytical options were chosen from the Bibliometrix software sidebar (Aria et al., 2021; Cuccurullo et al., 2016). This methodology is optimal for visual representations of the most relevant authors (in terms of scientific production with the presentation of their h-index), the most relevant university centres based on scientific production (with the most relevant affiliations indicated), the evolution of scientific production focused on the green energy transition in Germany (proposed based on the keywords plus analysis), and a conceptual map that outlines four types of themes in the research subject (Ciavolino et al., 2022; Zema et al., 2023). The data were imported to the Bibliometrix software in the form of a BibTeX file. The results of the *ad hoc* bibliometric analyses are presented in the results section. To maintain order in the article, VOSviewer bibliometric maps with descriptions are presented first, followed by the results of Bibliometrix analyses. The interpretation of these results forms the basis for the next section.

2. Research results

This section contains a bibliometric analysis of the green energy transition in Germany, based on queries 3-5 and the use of VOSviewer software, in which the bibliometric map depicted in Figure 1 was generated based on the 145 scientific publications distinguished by query 3, as shown in Table 1. The full counting method was chosen for the analysis of co-occurrences between indexed keywords. The minimum number of co-occurrences for a keyword was 10, and in total 23 of 1121 keywords met the threshold. The four clusters automatically identified by the VOSviewer software were coloured and presented in Figure 1 as a bibliometric map which illustrates the co-occurrence of keywords associated with the green transition in the German energy sector. Only "European Union" was deselected in the final VOSviewer dialogue box containing the suggested keywords (Zema and Sulich, 2022). At this aggregate level, associational themes or clusters of keywords that frequently occur together can be identified.

Figure 1. Bibliometric map of keyword co-occurrence results from Scopus based on original query 3



Source: own elaboration, generated in VOSviewer (version 1.6.18)

In Figure 1 the keywords "green energy transition" and "germany" do not appear, although these keywords were included in the query 3 syntax. The lines between the central nodes "energy policy" and "renewable energies" are thicker than the others, indicating that there are more co-occurrences of these keywords. The lines between keywords and their proximity indicate the frequency with which articles in the dataset use both keywords together. The keywords selected and utilised by the VOSviewer programme are listed in Table 2 and separated by semicolons. Regardless of the original writing style, the keywords in Table 2 are written in small letters, as per the unification procedure in the VOSviewer software. Automated bibliometric software created colour-coded clusters in Table 2, as shown in Figure 1. The number of keywords identified by the VOSviewer and represented as nodes in Figure 1 determines the order of clusters presented in Table 2. Clusters 1 and 2 consisted of six items, while clusters 3 and 4 consisted of items.

The presented clusters represent the different groups of keywords. In the red cluster, those keywords are related to the strategies or policies in the energy sector in Germany, while in the green cluster, environmental aspects are underlined (Zielińska, 2019). The relationship between fossil fuels and their environmental impact is presented in the blue cluster; in the yellow cluster, automatically distinguished co-occurring keywords present the economic and social effects of Germany's green transition, which may provide energy security (Wettengel, 2023).

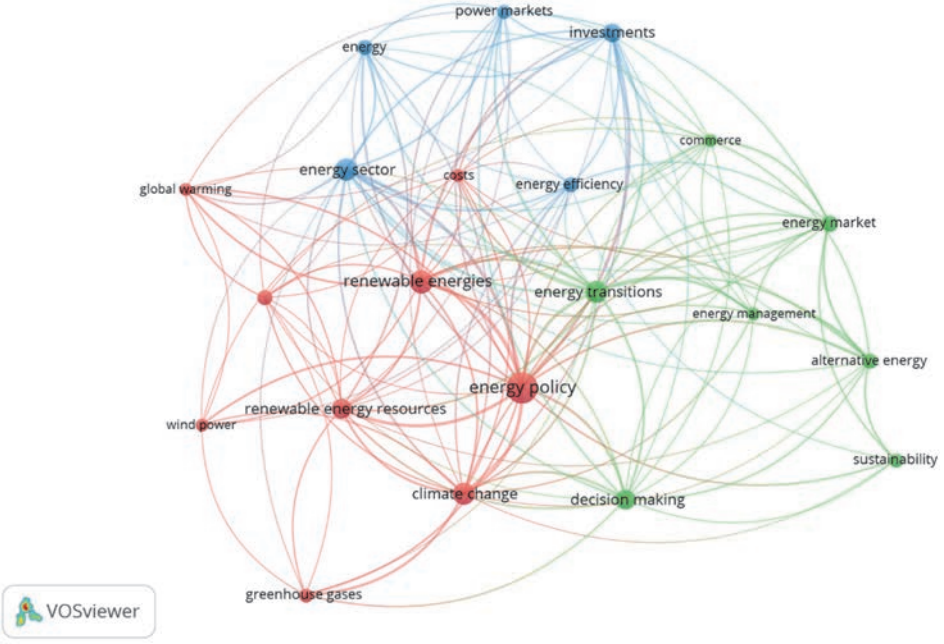
Table 2. Clusters of index keyword co-occurrences in Figure 1 for Scopus Query 3

Cluster	Colour	Keywords
1	Red	alternative energy, energy policy, investments, renewable energies, sustainable development, wind power
2	Green	decarbonisation, energy, energy efficiency, energy sector, energy systems, energy transitions
3	Blue	carbon, climate change, fossil fuels, gas emissions, greenhouse gases
4	Yellow	economics and social effects, economics, energy security, renewable energy source, renewable energy resources

Source: own elaboration

Based on the 73 scientific publications defined by query 4, as presented in Table 1, VOSviewer generated the bibliometric map shown in Figure 2. The analysis of indexed keywords co-occurrences using the full counting method was selected. The minimum number of co-occurrences for a keyword was five, and of the total 593 keywords, 22 met the requirement. The three automatically identified clusters were coloured by the VOSviewer software and presented in Figure 2 as a bibliometric map. In the final dialogue box of the VOSviewer programme, only "germany" was deselected from the list of suggested keywords.

Figure 2. Bibliometric map of keyword co-occurrence results from Scopus based on original query 4



Source: own elaboration, generated in VOSviewer (version 1.6.18)

There are three clusters automatically distinguished by VOSviewer (Table 3). The subnetwork subjects and keywords in red revolve around the energy policy, which is the biggest node in this cluster. This group of the most frequently co-occurring keywords is part of the researches dedicated to the climate changes counteracting and achieving sustainable development. The green cluster represents a more managerial approach; therefore, there are bigger "energy transitions" and "decision making" nodes in Figure 2. The smallest (blue) subnetwork is related purely to the economic dimension of the green energy transition in Germany (Ante et al., 2021).

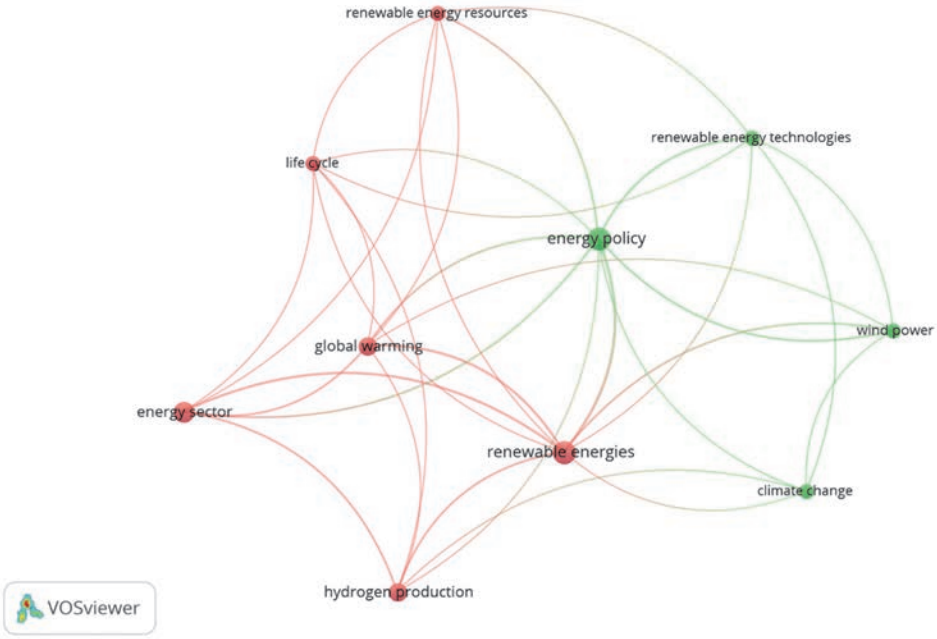
Table 3. Clusters of index keyword co-occurrences in Figure 2 for Scopus Query 4

Cluster	Colour	Keywords
1	Red	climate change, costs, energy policy, global warming, greenhouse gases, renewable energies, renewable energy resources, sustainable development, wind power
2	Green	alternative energy, commerce, decision making, energy management, energy market, energy transitions, sustainability
3	Blue	energy, energy efficiency, energy sector, investments, power markets

Source: own elaboration

The bibliometric map generated by VOSviewer is based on the 11 scientific publications distinguished by query 5, as shown in Table 1. The full counting method was chosen for the analysis of co-occurrences between indexed keywords. The minimum number of co-occurrences for a keyword was two, and 10 out of a total of 127 keywords met the requirement. The two clusters automatically identified by the VOSviewer software were coloured and presented in Figure 3 as a bibliometric map. None of the suggested keywords were deselected in the final dialogue box of the VOSviewer programme.

Figure 3. Bibliometric map of keyword co-occurrence results from Scopus based on original query 5



Source: own elaboration, generated in VOSviewer (version 1.6.18)

There are two clusters presented in Figure 3 and Table 4. The red subnetwork is related to renewable energies, the biggest node in this cluster after the "energy sector". The green cluster revolves around energy policy and wind power. The difference between them is visible in the deep analysis of the 11 literary publications (Table 1). The publications related to the green cluster assume a gradual transformation towards clean technologies, whereas the red subnetwork places more emphasis on direct change. Therefore, "hydrogen production" and "wind power" are the main different technologies.

Table 4. Clusters of index keyword co-occurrences in Figure 2 for Scopus Query 5

Cluster	Colour	Keywords
1	Red	energy sector, global warming, hydrogen production, life cycle, renewable energies, renewable energy resources
2	Green	climate change, energy policy, renewable energy technologies, wind power

Source: own elaboration

The bibliometric maps and their description subnetworks presented in this section are the result of narrowing the dataset of analysed publications. The results obtained indicate that there are different approaches to the green energy transition (*Energiewende*) in Germany. The differences reflect the scientific and professional discussion of the aims of the *Energiewende*, to which the analysed works contributed.

To complement the results achieved in VOSviewer, the analysis was also undertaken by means of Bibliometrix software in the R environment. The most relevant authors, in terms of scientific production expressed by NP (the number of published papers related to the green transition in Germany) and their h-indexes, were identified in Table 5. The results presented in Table 5 also distinguish less well-known indexes (Duan, 2023; Hofbauer and Limanskis, 2022; Pawliczek and Zimmermannova, 2018), the number of citations (times cited, TC) and the first paper on the topic published by each author (PY_start, year of first publication by a given author).

Table 5. Most relevant authors of publications related to the green energy transition in Germany

Surname and Initial	h_index	g_index	m_index	TC	NP	PY_start
Brodny J	2	2	0.5	99	2	2020
Cui Q	2	2	0.4	26	2	2019
Kiełkowska U	2	2	0.667	5	2	2021
Lema R	2	2	0.286	48	2	2017
Markandya A	2	2	0.25	107	2	2016
Pietrzak MB	2	2	0.667	5	2	2021
Skrzatek M	2	2	0.667	5	2	2021
Tutak M	2	2	0.5	99	2	2020
Wu Y	2	2	1	18	2	2022
Żuk P	2	2	0.667	10	2	2021

TC = Times Cited, NP = Number of Papers, PY_start = year of first publication by a given author

Source: own elaboration in Bibliometrix (version 4.1.2)

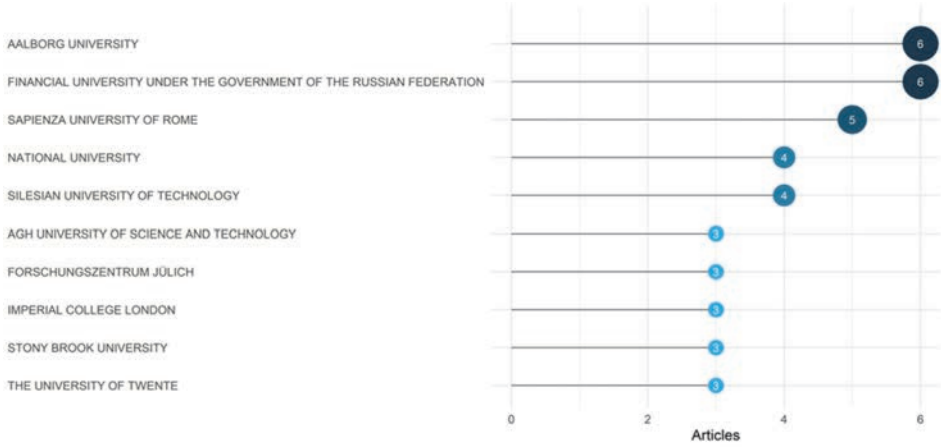
Table 5 presents the 10 most prominent scientists in alphabetical order with very similar indicators of their scientific production related to the green energy transition in Germany. The most influential of the scientists can be identified if their citations related only to the two papers are compared. In this case, it is not surprising that researchers working in Germany or Poland (J. Brodny and M. Tutak) are the leaders in this classification. The h-index presented in Table 4 has nothing in common with the authors' personal h-indexes (verified on 16 June 2023); for example, A. Markandya's personal h-index is 38 (with 220 documents indexed in Scopus), J. Brodny's personal h-index value is 29 (123 Scopus documents), and M. Tutak's personal h-index is 24 (91 Scopus documents). In contrast, the m-index, which is related to the h-index, is a rate-based measure which is calculated by dividing a researcher's h-index by the number of years that have passed since their first published paper. This index aims to quantify a researcher's impact and productivity, taking into account the length of their active career. Thus, it provides a measure of the 'rate' of their valuable contributions to their field.

Proposed by Leo Egghe in 2006 as an improvement over the h-index, the g-index is calculated based on the distribution of citations of the papers published by a given researcher. The g-index is the maximum reachable value of the h-index if a fixed number of citations can be distributed freely over

a fixed number of papers. In effect, A scholar has a g-index of g, if g represents the highest rank for which the combined number of citations received by the top g papers is at least equal g^2 citations (Table 4). This measure attempts to give more weight to more frequently cited articles.

The most relevant university centres based on scientific production (with the most relevant affiliations indicated) are presented in Figure 4. Together with the affiliations, the number of publications focused on the green energy transition in Germany indexed in Scopus is presented.

Figure 4. The Top 10 university centres by number of publications relating to the green energy transition in Germany



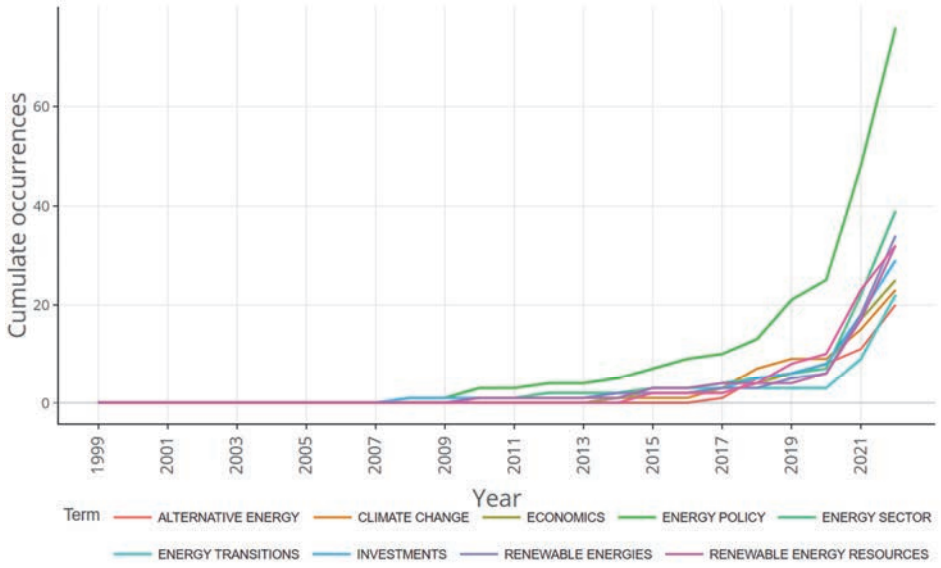
Source: own elaboration, generated in Bibliometrix (version 4.1.2)

The top 10 universities based on the number of papers published at each institution which are relevant to the green energy transition in Germany are listed in Figure 4. Based on the respective scientific output at each institution, the leading university is Aalborg University (Poulsen and Lema, 2017) in Denmark (which neighbours Germany) with six articles, the same number of publications as those published under the auspices of the Financial University under the Government of the Russian Federation. At two universities located in Poland (also a neighbouring country of Germany), the Silesian University of Technology (Brodny and Tutak, 2020) and AGH University of Science and Technology (Dyczko et al., 2021; Kowalska et al., 2022; Kudelko et al., 2013), four and three articles respectively were published on the topic. The National University of Ukraine also published four articles. Other universities high on the list as shown in Figure 4 include Sapienza University of Rome, Italy, and the University of Twente in the Netherlands (Heldeweg et al., 2015), which published five and four articles respectively. There are nine European universities among the list of 10 which are affiliated with the highest number of articles on the subject of green energy transition in Germany. This proves the significant influence of the German economy and the solutions introduced in the region in practice (Brodny et al., 2021; Żuk et al., 2021).

The evolution of the scientific production focused on the green energy transition in Germany was also analysed by means of Bibliometrix software based on keywords plus collection (Ciavolino et al., 2022; Zema

et al., 2023). The list of keywords plus in the timeline as cumulate occurrences is presented in Figure 5. The evolution of the research began in 1999, when "renewable energy resources" appeared as the first and predominant keyword related to the subject. Within the following years the collection of keywords expanded to include the nine terms listed in Figure 5. The most commonly used term is "energy policy" marked in green, when the other keywords appear less often in the context of the green energy transition in Germany (Röpke, 2013); however, they are strongly related to the topics of "energy transitions" and "investments" (Sulich and Sołoducho-Pelc, 2021).

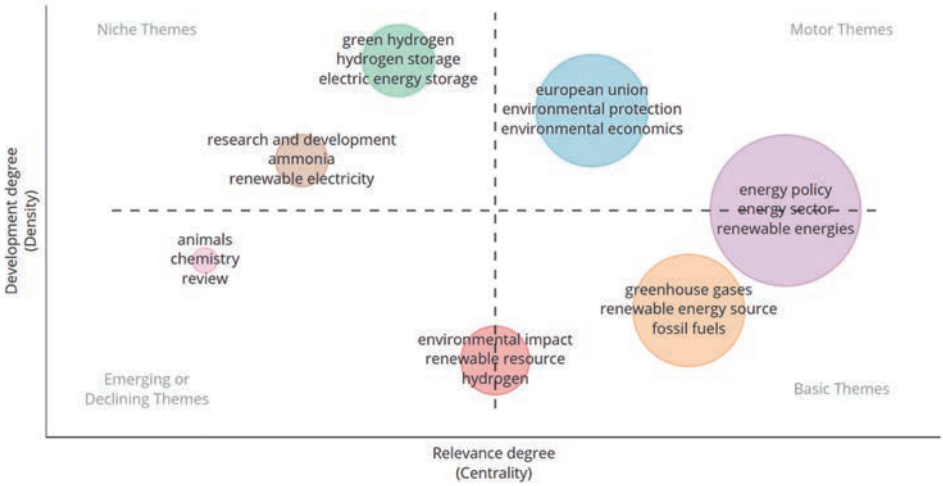
Figure 5. The evolution of keywords in publications on the green energy transition in Germany



Source: own elaboration, generated in Bibliometrix (version 4.1.2)

The results presented in Figure 5 correspond with the results of the analysis undertaken in VOSviewer as presented in Figure 1. The keywords "renewable energies" and "renewable energy resources" are very similar to each other. The further analysis of the keywords plus automatically distinguished in Bibliometrix software (Zema et al., 2023) provided a conceptual map that outlines four distinct themes pertaining to the research subject, as shown in Figure 6.

Figure 6. Thematic map of publications



Source: own elaboration, generated in Bibliometrix (version 4.1.2)

The upper right-hand quadrant of the thematic map, represented in blue and labelled 'motor themes', highlights the core and mature themes in the field of green energy transition in Germany. These themes have received substantial attention in the research context and are associated with keywords such as "european union", "environmental protection", and "environmental economics". The significance of these themes is reflected in the prevalence and high citation counts thereof, representing well-established areas of research (Zema et al., 2023). These subjects could be linked to policies, regulations, and economic incentives implemented by the European Union to promote renewable energy sources and mitigate the environmental impact (Herberg et al., 2020; Rubin et al., 2007).

In the top left corner of Figure 6 are the 'niche themes' symbolising emerging areas that, while not yet thoroughly explored or highly cited, hold promise for future research. This research gap is illustrated by the green cluster, revolving around "green hydrogen", "hydrogen storage", and "electric energy storage", and the brown cluster, encompassing "research and development", "ammonia", and "renewable electricity". These clusters may suggest developing trends or areas of interest in the field that are beginning to gain traction (Ciavolino et al., 2022). The 'niche themes' represented by the green and brown clusters point towards a potential shift in focus towards green hydrogen (Chai et al., 2021), energy storage technologies (Hoffart et al., 2021), and innovative research in the areas of renewable electricity and ammonia. These could represent the emerging technologies and strategies that are likely to become more important in the future, especially in the German context where there has been a strong emphasis on clean energy technologies (Rogge and Johnstone, 2017; Röpke, 2013).

In the third quarter of the thematic map in Figure 6, 'emerging' or 'declining' themes are represented, displaying a dynamic landscape. The small pink cluster, which contains "animals", "chemistry", and "review", represents themes that are either gaining momentum or diminishing. The red cluster, which intersects with the fourth quarter and encompasses "environmental impact", "renewable resource", and "hydrogen", signifies a bridge between emerging themes and basic, established ones. Furthermore, the overlap of the red cluster with 'basic themes', including

"environmental impact", "renewable resource", and "hydrogen", may suggest that these topics, while established, are undergoing renewed investigation or transforming due to advancements or changes in the field (Kuchta et al., 2017; Kwilinski et al., 2023).

In the fourth quadrant of Figure 6 are 'basic themes', representing foundational themes that have consistently been the focus of research. While they may not be as frequently cited as motor themes, they are essential to a deeper understanding of the topic of the green energy transition in Germany. This quarter is not only characterised by its intersections with the others, but also by an independent light orange cluster that contains the keywords "greenhouse gases", "renewable energy source", and "fossil fuels". This indicates a solid base of research focusing on these fundamental aspects of environmental study (Borodina et al., 2022; Heldeweg et al., 2015). The continued focus on these areas shows their importance in the energy debate and that they remain central to the transition towards a green energy future in Germany. Overall, this thematic map provides an overview of the research landscape in the field of the green energy transition in Germany. The different clusters of themes (Figure 6) highlight the areas of core, emerging, and future importance, presenting an evolving snapshot of this field of study.

3. Discussion

Germany has a significant influence on the energy policies of neighbouring countries (Mortensen, 2022; Naumenkova et al., 2022). Changes in the strategies used in the energy sector are frequently described in scientific publications indexed by Scopus by researchers who collaborate with businesses (Mathur et al., 2019; Yushchenko and Patel, 2016). This kind of close cooperation between academia and the business environment towards achieving sustainability in the energy sector has already had an effect in Germany. As a result, scientific works frequently reflect pro-environmental changes in Germany's energy sector strategies. The topic of the green energy transition in European countries has saturated the research community in recent years, although the number of scientific publications is still increasing. Both theoretical and empirical research provide a vast number and variety of patterns and models for other countries to follow in their own green energy transitions.

The goal of this paper was to evaluate the "green energy transition" in Germany by providing a meaningful representation of how scholars and their Scopus-indexed publications pertaining to the green transition have structured the concept. In this paper, it is assumed that scientists, as the authors of the explored publications indexed in Scopus, influence business strategies and cooperate with business. Therefore, their works reflect the changes in Germany's energy sector, and there is close collaboration between academia and the business community to ensure the sustainability of the sector (Sulich and Sołoducho-Pelc, 2022). Due to the descriptive nature of those studies, bibliometric analyses of the green energy transition in Germany are a rare subject in the literature. Given the interpretative nature of this area of study, it constitutes theoretical sampling rather than statistical sampling, supported by the graphical representations of bibliometric maps. This sampling strategy captured the nested nature of multiplicity in the field, and the articles analysed are meaningfully representative, although by no means exhaustive.

The choice of the Scopus database has inherent limitations, most notably the fact that some of the newer journals are not indexed in these systems. The Scopus database requires a standard academic subscription, which can be a source of limitation for those who would like to replicate this study.

Following on from this issue of accessibility is the structure of the data that can be exported from databases.

It is important to acknowledge the three main limitations of bibliometric analysis. First, by focusing on keyword analysis and keyword co-occurrence patterns, the methodology is inherently retrospective and predisposed to highlight patterns concentrated around the most important keywords. Another limitation is that only the frequency and popularity of the keywords in scientific publications are presented, without either a positive or negative context. Furthermore, the longer the publication is in print, the more opportunity it has to circulate and influence other publications. While acknowledging this as the second limitation, there is a strong suggestion that bibliometric analysis can offer a corrective effect to the recency bias that tends to benefit older publications. The third limitation is the scope of the paper introduced by the query syntaxes used. One way to overcome this problem is by exploring interdisciplinary areas that highlight the connections with the green energy transition in Germany. This is a limitation of the SLR method related directly to the formulation of queries. Regarding the queries, the limitation in the query syntax and the results generated by the VOSviewer software.

This review set out to raise more questions related to the strategies used in the energy sector (Sołoducho-Pelc, 2016). The maps generated in this study are meant to generate curiosity as much as to offer a definitive reading of the literature.

Conclusions

The main conclusion of this paper is that the changes in the German energy sector towards more green and sustainable strategies are reflected in scientific literature. The scientific contribution of this paper is the presentation of the existing research in published scientific papers on the subject of the green transition in Germany and a proposition for the classification of the pattern of this economic change. The bibliometric study based on the SLR variation method with queries is an initial step in the exploration of the research problem developed by means of Bibliometrix software analysis. This study identifies, explores and covers multiple research gaps. The proposed order of queries, bibliometric maps, and the clusters thereof address the taxonomic research gap in the present study. The second knowledge gap relates to the study, while the methodological research gap is addressed by combining the two adopted methods. The final research gap addressed in this study is based on limited literature reviews and publications devoted to the transformation of the German energy sector. The methodological contribution of this paper is based on a comparison of the descriptive and SLR literature review methods employed in the current study. This research procedure opens the way for the replication of bibliometric research, strengthening the development of management science (Graczyk, 2021; Kozar and Sulich, 2023). A further scientific contribution is the detailed description of procedures that assure the reproducibility of the paper by other authors.

The practical contributions of this paper may interest researchers, managers, and policymakers interested in changes in the energy sector in Germany. The direct implication for policymakers is the visible creation of two directions for green strategy: slower, more gradual change, or faster and more direct change. This choice is a specific direction of the development of green strategies in the German energy sector and involves both organisational and technological solutions.

The originality of this paper is based on the usage of combined methods of analysis of bibliometric maps and the description

thereof. The visualisations present the relationships between patterns of green transition formulation. Bibliometric maps, together with the results of Bibliometrix analysis, prove the trends in science and inform other authors about the general progress or research gaps in the explored interdisciplinary field. The novelty value of this research lies in the presentation of the existing research gaps and the identification of the main directions of ongoing research on the green energy transition in Germany. One potential avenue for further research would be additional analysis using other kinds of bibliometric software combined with secondary statistical data analysis. Another possible form of analysis could be focused on other countries or groups of countries, and present the influence of the German green transition on the local energy sector.

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