sciendo

Advancing the Knowledge Economy in the Energy Sector: A Bibliometric Study of Global Research Dynamics

Ștefan MARGARITESCU
Bucharest University of Economic Studies, Bucharest, Romania
margaritescustefan19@stud.ase.ro

Claudiu TUDORACHE
Bucharest University of Economic Studies, Bucharest, Romania
tudorachecladuiu17@stud.ase.ro

Abstract. *The energy sector is one of the most essential areas facing a large number of challenges from climate change and resource depletion to the need for sustainable development. At the same time, the knowledge economy is a comprehensive system in which innovation, cooperation, and efficiency incentives interact. The current paper is a bibliometric study of the state of global research in the field of the knowledge economy and the energy industry. As a result, the most critical vectors, leading authors, and emerging topics are identified. The VOSviewer algorithms have helped to consider the joint authorship networks, citation patterns, and keywords using the dataset of 1796 documents from Scopus. The final result is a set of trends demonstrating the cross-discipline synergy near the future, including the knowledge-based research of the energy sector, energy innovativeness, knowledge dissemination, and digital transfer. Therefore, they are important, as they promote the aggressive development of sustainable energy. Who are the leaders of the future? The authorship institutions and researchers of environmental science, engineering, and economics. Moreover, the pattern of cooperation of countries and organizations is noticeable. Additionally, the future is determined by digital technology, knowledge in the field of renewable energy, and international cooperation.*

Keywords: Knowledge Economy, Energy Sector Innovation, Knowledge Transfer, Energy Transition, Renewable Energy, Digital Transformation in Energy, Bibliometric Analysis.

Introduction

The changing power dynamics and stronger demand for rectifying global problems such as climate change, resource overexploitation, and the imperative need for sustainable development or transition have played a great role in the transformational evolution of this present structural business of the energy industry. Knowledge Economy is an organizing framework for harnessing innovation, collaboration, and efficiency in such rapidly changing settings. This model underlines the vital role of harboring intangible assets for driving economic growth and societal welfare, including expertise, research, and technological advancement. Hence, knowledge economy has led to several novel opportunities for the energy sector to move through energy transition, use resources more effusively, and boost global energy security. Knowledge economy is quite applicable to innovations such as renewable energy engineering, smart grids, and storage technology and also accommodates working together for foreign cooperation to exchange intellectual property across the borders and establish globalism alliances to fight the shared energy-related dilemmas. The interactive impact of knowledge economies attracts less attention in academic research. The developing trends and central players of knowledge economy are not visible in the existing literature, particularly for the energy industry. A major broad-based bibliometric approach has been used to examine the changing pattern of intellectual production in

DOI: 10.2478/picbe-2025-0371

the energy sector. This technique combines co-referring papers, keywords, and mapping as well as a temporal trend or cluster analysis which focuses on changes in the intellectual landscape and growing subfields in energy research. The network of foreign collaboration has also been analyzed as well as a geographical analysis of research results to objectively identify top contributors and competitiveness hubs in intellectual production on the energy sector. Our research asks some basic questions: What segmentation and topics emerge when we analyze the knowledge economy within the energy industry? Who are the major players or institutions driving research efforts in this field? How do international collaboration networks impact the flow of knowledge in this domain? Our hypothesis is that the knowledge economy in the energy industry is becoming increasingly transdisciplinary, as shown by a convergence of innovation, policy, and sustainability. By achieving this point, we hope to better understand how knowledge economy actually influences the future of energy, while also creating innovation and collaboration opportunities to address some of the world's urgent energy issues.

Literature review

Theory that could explain these connections within the scope of the modern energy sector is vital to develop these ideas further. The issue of knowledge transfer has long become a focal aspect of practically underpinning the global energy transition, and knowledge-based economies, more generally, as supporting the integration of innovational technologies into economic and social processes. The following paper aims to critically analyze relevant literature on the topic of knowledge transfer and green economy, focusing on the digital transformation trends in the energy sector. The study aims to argue that the examined concepts are critical to ensuring both economic and ecological sustainability. Brătianu and Dincă provide a comprehensive definition of the knowledge-based economy and may present it as a necessity framework for understanding the role of knowledge transfer for energy development.

Another major theme is the concept of the green economy, namely "a structured-based method of natural resource management and environmental impact mitigation". According to Mo et al., transition to a green economic framework is critical to achieving the environmental targets, for example, highlighted in the Paris Agreement. This involves new concepts such as renewable energy, the circular economy, and innovative resource utilization. Another suggested idea Kristia & Rabbi, 2023 that also displays close relationship with energy in the circular economy how renewable energy can be also reutilized to reduce waste and increase efficiency of multiple economic processes. The area of knowledge transfer in energy is an interlinked multi-faceted area of economic, socio-cultural, and technology relationships. In respect Dejan Ridjan, Marinela Petrovic, and Nada Grigorescu 2022, successful operation of renewable energy framework is reliant on an active cooperation pattern that envisages information and resource exchange between states and entities. Within the European Union perspective, which has developed a strong integrated framework of common policies and regional projects to promote sustainability, this structural connection is vital. At the same time, however, the power of knowledge transfer exhibits specific challenges ranging from shortcomings in a singular legislative framework to the structural mismatch between economic and societal priorities. Digital transformation, which is one of the major determinants of current market dynamics, includes the implementation of digital technologies into operational and strategic activities. Offering substantial opportunities in cost reduction and sustainability promotion, this framework requires heavy infrastructure and digital education investments.

The three key components: the knowledge economy, the knowledge transfer, and the digitalization seem to be the most crucial in order to understand what happens within the energy sectors. Finally, the concluding part will present the overview of the mutually connected components in developing the sustainable energy economy, considering global trends, and identifying research gaps. The current analysis shows that knowledge transfer within the energy sector should not be viewed only as a tool for information dissemination but as an all-encompassing process of integration, further innovation, and collaboration. In recent studies, it has been argued that the success of knowledge transfer heavily depends on the regulatory framework that will allow for the most profound transfer of expertise between the institutions, organizations, or countries. As it has been mentioned by Grigorescu et al.: "European Union member states have implemented heterogeneous strategies to promote KETs, which has created a variety of opportunities and challenges to align their objectives". At the same time, looking at the global trends from the prism of digitalization and using the bibliometric analysis instruments will lead us to analyze how the formal knowledge transfer happens. For example, the study of used bibliometric analysis to map key research areas in energy management and found out that the focus of research has substantially shifted on digitalization and the international aspect of cooperation. This shows how much reasonedness and methodological accuracy one should have to understand the basis dynamics of the sector in focus. Lema and Lema come up with the relevant examples from India and China: for the green energy sector, particularly, for wind and electric vehicles, the technology transfer became possible only due to local innovation and strategic acquisitions.

Kristia & Rabbi presented another example that displays such opportunities. However, they argue that the knowledge that is disseminated between firms and institutions would significantly diminish the abovementioned cost and process efficiency [25]. For that reason, the contribution of knowledge ecosystem on a joint production is crucial for a country that intends to reach sustainability goals. As the research of Świątowiec-Szczepańska and Stępień suggests, the digital transformation has also somehow helped to assist in such transformations. More specifically, they point at optimization of operational processes, facilitated by AI and big data, which have proven to detect the innovative solutions for issues that the energy sector has been struggling with for a prolonged period. Nonetheless, the formation of such integration remains a cumbersome process with significant investments made for such infrastructure and human capital training. Indeed, due to the mentioned diversity or dynamism, the knowledge transfer in the energy sector can vary from the regional innovation process when it comes solely to the national interest to global projects of international collaboration. Looking at the ongoing trends, it becomes obvious that development in this dimension is only possible with the utilization of connectionist integration platform of knowledge and technologies. Thus, consideration of the issues in detail will remain among the priorities of researchers as well as a practical sphere of proficiency. However, despite the progress achieved in knowledge linkage and the implementation of the innovations into the energy sector, there may be serious obstacles that would not allow the advancement initiated by this process to be fully completed. The central problem mentioned in the work of Grigorescu et al. from 2022 is the absence of a comprehensive legislative framework and coherent policies practiced internationally that would undoubtedly promote better cooperation among the states. These obstacles eradicate the efficiency regarding knowledge transfer and produce disparities in the availability of the resources and technologies.

Another vital factor contributing to this is the technological and economic disparity between fully developed and emerging states. Even though renewable energy technologies are becoming more and more widespread, their capital-intensive baseline cost, combined with the lack

of investment, is 'probably the most stringent enforcement mechanism.' The assertion of "Managing Technology Transfer Challenges in the Renewable Energy Sector" is supplemented with a claim that financial matters are not the only barrier: intellectual property, the overall issue of cultural and educative resistance to change, and the lack of an educational structure supporting skill-building are also mentioned. The authors follow this up with that professional preparation coupled with access to open-source technologies delivers a feasible method to alleviate everything except the first issue. Methodologically, the bibliometric analysis can accurately and precisely determine the research vacuum that researchers should invest effort into. In line with this, "advanced bibliometric analysis can design a clear picture of global trends, allowing researchers to focus on challenges that require attention the most, as artificial intelligence analyzing bibliometric data sets help identify outliers that remain undiscovered." However, the question remains: how can all those trends be tied together effectively to create an energy sector sustainable? The paper already has multiple instances on how that was realized, as reported by Lema & Lema : how China and India managed their way to renewable independence. However, as Baas et al. also remarked, there is much to study there. Thus, a deeper understanding of how international cooperation influenced the energy sector can provide yet another area for remodeling.

To conclude, knowledge transfer in the energy sector can be regarded as a very important and quite complicated process that is affected by a variety of economic, social and technological forces. Although some of the recent developments have certainly been positive and promising, many knowledge exchange phenomena, in fact, remain terra incognita. Thus, it would make sense for the future scholarship to focus on the studies concerned with creating engineering methodological and strategic frameworks, and achieving a much-needed balance between a locality's vested interests and global trends by doing so, encouraging a much more sustainable energy transition. Such literature, in return, would help generate a much-needed stimulus for further research from this perspective, which will focus not only on technological advancements, but on the construction of the intricate and robust sustainable knowledge systems. This study could propel the research in the field in the more right direction, as it has tried to approach the interactions between policies, technology and knowledge from a rather detailed and informative perspective.

Methodology

To answer the three research questions, which were introduced before, a bibliometric analysis, as a quantitative research method, was chosen. By delving into the Scopus, a database, which was established by Elsevier, bibliographic information was retrieved. Scopus was chosen due to the vast quantity of publications and the journals' high quality as it was described by Baas et al. who present their work on Scopus as "it is a carefully structured and well-organized database which is highly beneficial for bibliometrics analyses". The databases allow to find the most influential works and authors and also to identify potential flowering trends, such as the transition from traditional to renewable energy sources. The Research was conducted in December, 2024, by using keywords "knowledge economy," "energy sector," "energy sector innovation," "knowledge transfer," "energy," "knowledge on renewable energy," "digital transformation," and "energy". Sampling was made on "Article title, Abstract, Keywords," without a limitation for years, but confined to key domains that included "Engineering," "Energy," "Environmental Science," "Business, Management and Accounting," "Economics, Econometrics and Finance," "Chemical Engineering." After excluding the options that were irrelevant to the query, 1796 documents remained. For the elementary analysis, the basic characteristics of the Scopus were used, such as the export of citations, bibliographic data, abstracts, keywords, and funding and other relevant

information were exported in CSV file format, and then the intended software, VOSviewer was selected for further processing. To analyze bibliographic information, VOSviewer software was applied to extract usage and term clusters that had to be observed on co-authorship maps, co-occurrence maps of keywords, and clusters, which were generated based on citations. Powered by this software, the visual characters of the research scene, concerning collaboration based on the co-authorship networks and co-occurrence maps, and more, which could be related to the directions of future development in research in the energy field, emerged in the analyses.

Results and discussions

In the high-speed era of global technological evolution and energy transition, this knowledge economy is an overarching driving force of innovation in energy technology. This bibliometrical study views the change of the global research dynamics perception in the energy sector and displays emerging tendencies and collaborative networks as well as central focal points that will drive the future of knowledge production and distribution on energy. Figure 1 presents the time series progress of high-research-interest publications on the knowledge economy within energy. From 1988 to 2012, this was a relatively static journey with very small outputs for that year. Yet, from 2015, there is a rather clear and robust upward trend showing engagement with the scholars in the field. The last decade or so is obviously connected to the global move toward energy transition, renewable energy, and digitalization, which should have triggered academic attention and interest. The peak in 2024 highlights the urgent topics in fighting what seem to be the challenges of our days, namely, climate change and sustainability. Thus, this increase in this up-trending line positions the interdisciplinary studies, international collaboration, and innovation as increasingly important.

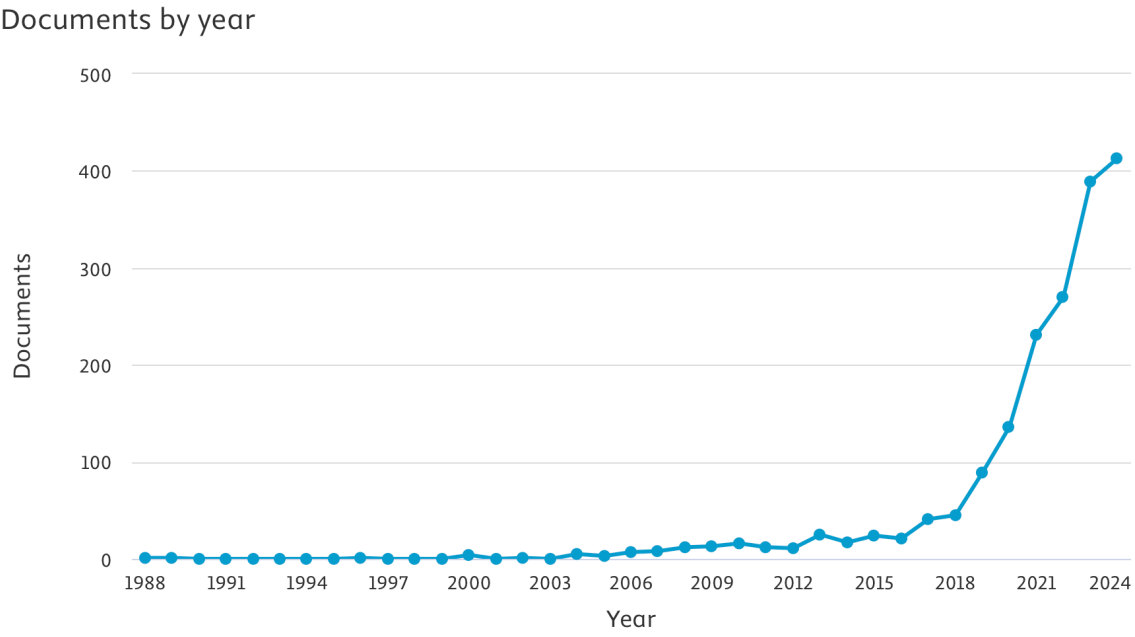

Figure 1. No. of publications per year

Source: Authors' own research.

Considerably differently, the scale in the places of distribution of research on the knowledge economy in the energy sector is represented in Figure 2. The places of distribution steer that China is considerably ahead of other countries in presenting nearly 450 publications. It guarantees the high priority of energy innovations, renewable energy technologies, and digital energy transformation. The United States is close, illustrating a strong research agenda and commitment to the sustainability of the energy spectrum. Russia, Germany, and the United Kingdom convey a solid portion of the distribution. It hints at their overall image of robust contributors to the power industry through engineering advancements and a policy-oriented perspective in research. India and Italy are also on the chart, showing a more subtle presence but presumably announcing interest in utilizing the knowledge economy for energy progression. Norway and France also host research of this kind. The picture shows numerous international collaborations that stimulate the sharing of expertise in energy shifts.

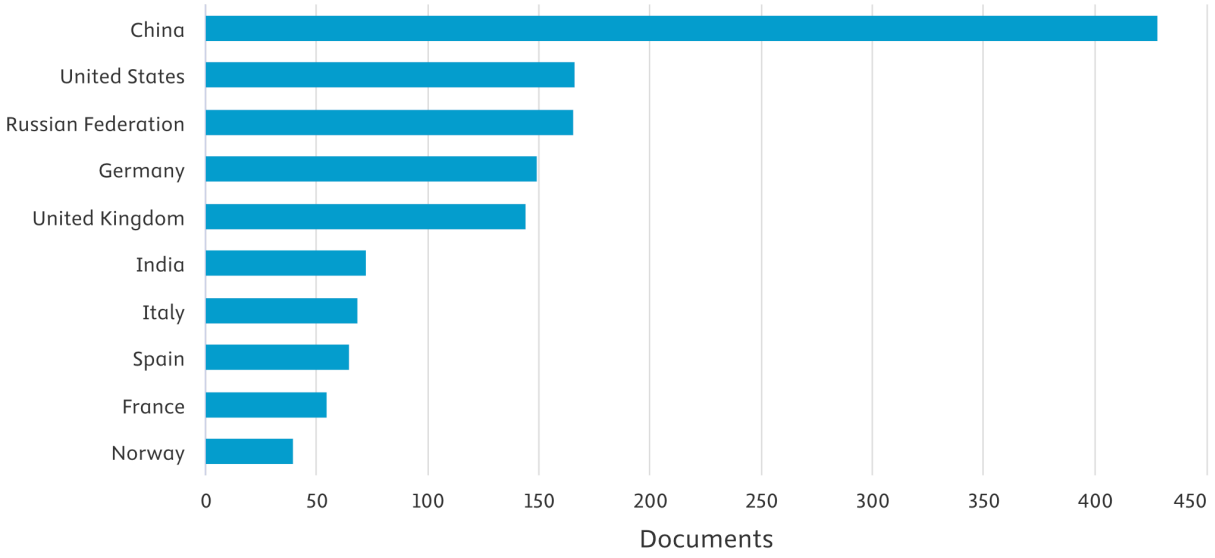

Figure 2. No. of publications per country

Source: Authors' own research.

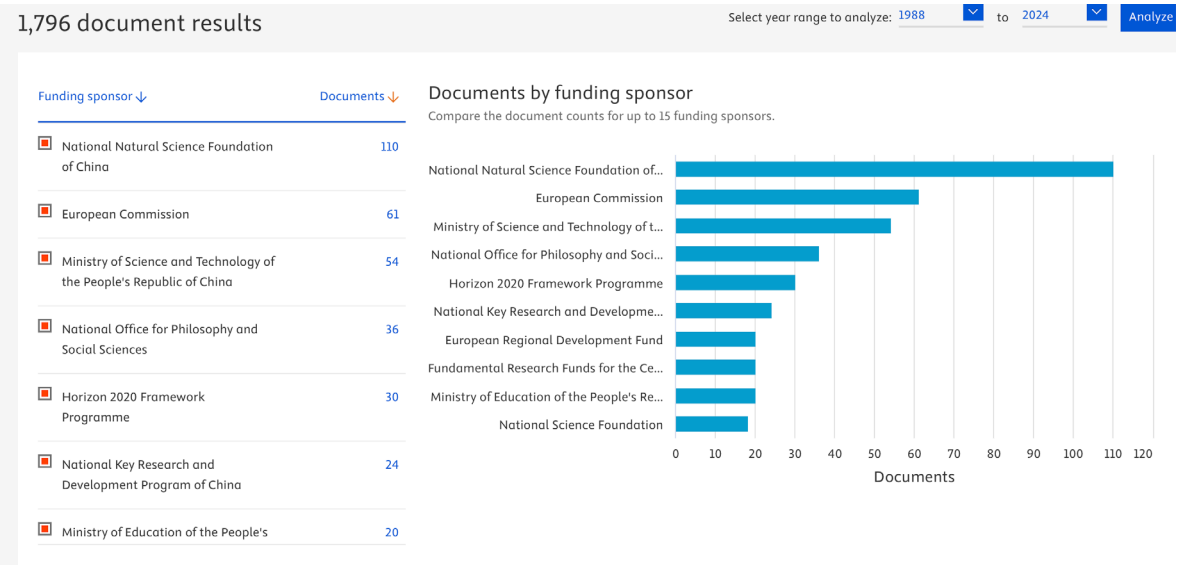

Figure 3. Main funding sponsors

Source: Authors' own research.

Figure 3 below, on the other hand, illustrates the key funding sponsors on research landscapes in the knowledge economy such as the energy sector. The National Natural Science Foundation of China emerges as the largest sponsor with twelve documents funded. This may explain China's dominance in Figure 2 above on country-wise publications. Arguably, the experimental piece of evidence here shows China's robust investments in research and innovation concerning energy sustainability and technological development. For instance, even the European Commission has sponsored Horizons 2020 alone funded 30 documents highlighting the union's agenda to enhance a common group research agenda versus energy transition. Notable sponsors in this field are the Ministry of Science and Technology of China and the National Office for Philosophy and Social Sciences implying an approach in China that cuts across energy towards integrating both technical and socio-economic pillars. The European Regional Development Fund further reveals Europe's approach in regional collaborations concerning the broader energy transition. Connecting the funding sponsors and outputs through the revealed linkage above provides empirical evidence that targeted funded schemes play a crucial role in transforming the research landscape globally. From the link between the two figures above, it is visible that countries that produce a massive volume of papers is well-rewarded through a comprehensive funding ecosystem, innovation and international collaborations. Arguably, such strategic investing is crucial as it drives the main research fronts of the knowledge economy, including solving global energy issues.

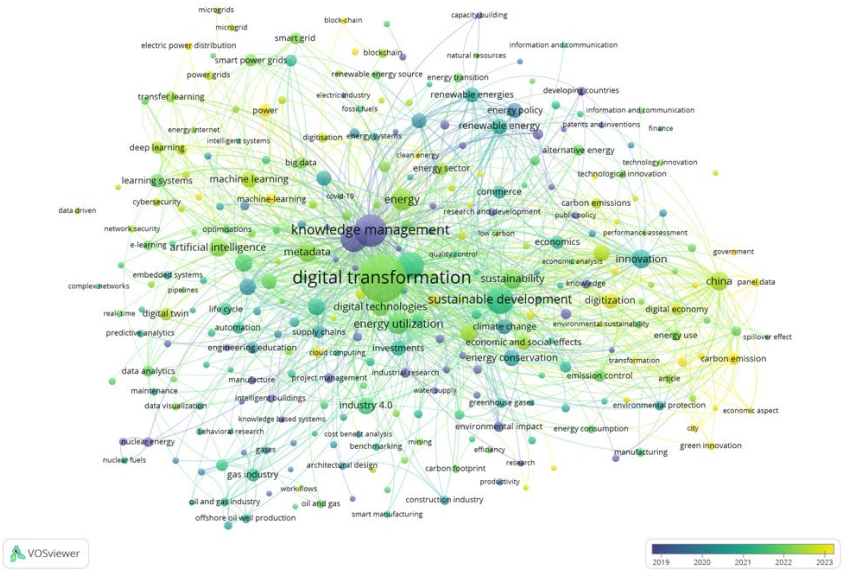

Figure 4. Keyword co-occurrence in overlay visualization

Source: Authors' own research.

This Figure is the most important visualization of all major topics and their interconnections in the field of KBVE for the energy sector. The leading nodes, digital transformation, knowledge management, sustainable development, are accordingly the most vivid points influencing further interaction and innovation that forms a research domain. The color contrast between the lead blue topics that have already left the scope: renewable energy, energy conservation, and the yellow ones: artificial intelligence, machine learning, and blockchain emphasizes the transformation of research priorities. As evident, the role of digitalization has been dramatically increasing in recent years as an ultimate solution to the problems of sustainability and energy efficiency. The VR graph shows the strong interrelatedness of all keywords forming the interdisciplinary field that also includes environmental science to all areas of advanced technology and policy making and using them to build pathways to the energy transition.

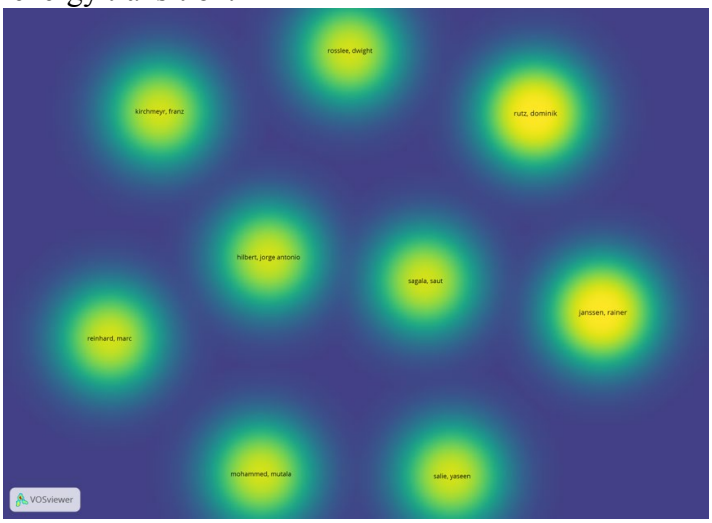

Figure 5. Most cited authors in density visualization

Source: Authors' own research.

Figure 5 presents the most prominent authors in the ranking. Each of the bright clusters, highlighting the highly cited authors as Hilbert, Antonio, Rosslee, Dwight, Rutz and Dominik, indicates low overlap of the emphasis areas between these authors. This low overlap suggests that these authors establish distinct specialized domains in this field, not optimizing research themes for research integration. This lack of convergence among these clusters indicates a plethora of approaches and topics in the huge interdisciplinary field. Similarly, independent contributions form a dispersed pattern of the total research landscape.

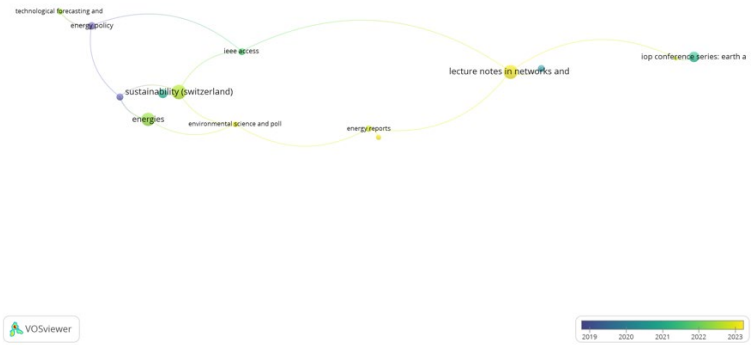

Figure 6. Most Cited Journals and Sources Referenced in Network Overlay Visualization

Source: Authors' own research.

In Figure 6, one may see the most referenced journals and sources in the knowledge economy research within the energy field. The matching decipher other temporal movements, where some of the predominating sources are transitioned from the older such as Technological Forecasting and Social Change, to Energy Policy in blue, to newer publication, such as Lecture Notes in Networks and Systems and IOP Conference Series: Earth and Environmental Science in yellow. The discretely separate groupings not only indicate that the journals cater to certain themes in the field with very limited synergies, but also that such journals may include sustainability-oriented journals, environmental-science journals, and digital systems journals. The movement from traditional energy policy discussions to digitally driven networks enhances the field's comprehension towards contemporary challenges like digital transformation and the interdisciplinary collaboration, which may unfold within the energy research. The visualization therefore indicates more diverse publication platforms defining the knowledge landscape within the dynamic energy-working space.

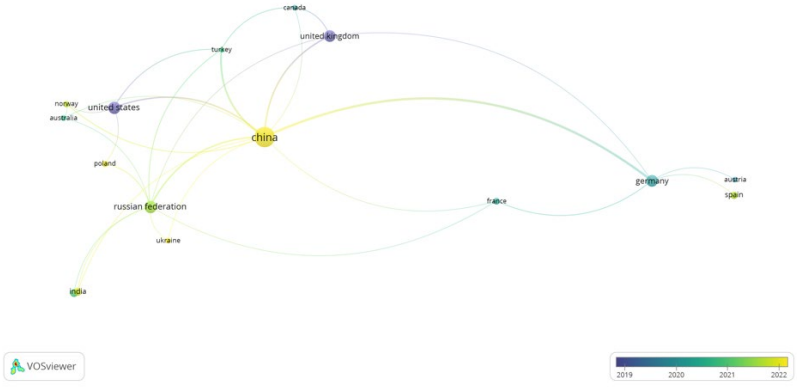

Figure 7. Citation country network analysis

Source: Authors' own research.

The international collaboration network on research for the knowledge economy in energy is depicted in Figure 7. China is the hub connecting a large part of the globe, and it is linked to countries that feature exceptional connection with these partnerships, such as the United States, Russia, and the United Kingdom. The colors forming a series, which reflect stages of the collaborations, involve the recently made links, making visible the partnerships, especially those the most current with Germany and Spain among other links. The picture provided in the description reveals certain well-defined regional clusters and is very eloquent in showing the strategic connection of the central part with countries such as the United States and the United Kingdom. Therefore, the importance of Cross-nation collaborations is observed as the source of Novelty promotion and knowledge flow that collaborated well with the output of insights with the covered dominance in this by China. The tendency towards increasingly interconnected landscapes serves as the evidence of the global approach to most of the urgent energy problems and argues for the collaborative development and innovation measures.

Conclusion

The results of this article aim to uphold and outline the dynamics of the knowledge-based economy in the energy sector obtained through worldwide research-based bibliometric analysis. The study implications indicate critical contributions of knowledge transfer and aid in fast-tracking the informalization of sustainable energy generation characterized by technological adoption and international cooperations. The number of publications rapidly increased from 2015 showing a growing interest of the academia afterburn prior questions like climate change and sustainable developments become priorities regarding the agenda of the government, the industry, and academia. All articles examined the dynamic interrelationships between engineering, environmental sciences, and the economics department, designed to nurture knowledge-based economic revolution. The study findings indicate led digitalization, renewables technology innovations, and international corporative, which are indeed premises leading to a sustainable future. More so, it is evident that applied technology such as AI and Blockchain will determine the future of the energy sector. Some limitations were evident in this research. Empirical data collection did not entail the direct observation for alignment to the real-life scenario possible. Further, the culture and economic factors, which are equally critical in determining knowledge transfer, were very briefly described. This apparent gap would require expanded exploration including case studies and empirical data collections for elabsct insights. In the future, a better understanding of the presented studies focus is knowing the level of knowledge transfer effectiveness on the regional level and appreciating the importance of cultural context and locally frame strategies. Questionnaires or further interviews with additional empirical insights into the interaction between the organization and the state in such a cooperations could supplement the understanding. Creating a political and economic framework enforcing the digitalization and international corporative efforts that support knowledge transfer is yet another mile that needs to be explored. In conclusion, the article has indicated vast milestones in the long journey ahead to have insight knowledge transfer dynamics in the energy sector. However, despite the significant achievement, there are still dark spots to explore. Future studies should examine policy-technology, and corporative interaction with the aim of creating sustainable and trying on collectively discussed solutions. Hence this study marks the fear of innovations and knowledge-based economic from a new dimension of global energy transition.

References

Baas, J., Schotten, M., Plume, A., Côté, G., & Karimi, R. (2020). Scopus as a Curated, High-Quality Bibliometric Data Source for Academic Research in Quantitative Science Studies. In *Quantitative Science Studies* (Vol. 1, Issue 1, pp. 377–386). MIT Press. https://doi.org/10.1162/qss_a_00019

Brătianu, C., & Dincă, V. (2010). Knowledge Economy Dimensions. [Detalii suplimentare din sursa originală].

Grigorescu, A., Ion, A.-E., Lincaru, C., & Pirciog, S. (2022). Synergy Analysis of Knowledge Transfer for the Energy Sector within the Framework of Sustainable Development of the European Countries. In *Energies* (Vol. 15, Issue 1, p. 276). MDPI AG. https://doi.org/10.3390/en15010276

Kulkarni, S. K., Harichandan, S., & Roy, B. (2022). Bibliometric Analysis of the Research on Hydrogen Economy: An Analysis of Current Findings and Roadmap Ahead. In *International Journal of Hydrogen Energy* (Vol. 47, Issue 20, pp. 10803–10824). Elsevier BV. https://doi.org/10.1016/j.ijhydene.2022.01.137

Lema, R., & Lema, A. (2012). Technology Transfer? The Rise of China and India in Green Technology Sectors. In *Innovation and Development* (Vol. 2, Issue 1, pp. 23–44). Taylor & Francis. https://doi.org/10.1080/2157930X.2012.667206

Managing Technology Transfer Challenges in the Renewable Energy Sector. (2022). [Detalii suplimentare din sursa originală].

Mo, R., Peng, X., Wang, S., & Zhang, J. Z. (2024). Knowledge Mapping of Green Economy Research: A Bibliometric Analysis. In *Sage Open* (Vol. 14, Issue 4). SAGE Publications. https://doi.org/10.1177/21582440241293581

Kristia, K., & Rabbi, M. F. (2023). Exploring the Synergy of Renewable Energy in the Circular Economy Framework: A Bibliometric Study. In *Sustainability* (Vol. 15, Issue 17, p. 13165). MDPI AG. https://doi.org/10.3390/su151713165

Świątowiec-Szczepańska, J., & Stępień, B. (2022). Drivers of Digitalization in the Energy Sector—The Managerial Perspective from the Catching Up Economy. In *Energies* (Vol. 15, Issue 4, p. 1437). MDPI AG. https://doi.org/10.3390/en15041437

Szarucki, M., Rybkowski, R., Bugaj, J., & Bracio, K. (2022). A Comprehensive Review of Research Approaches in the Energy Sector: A Management Sciences Perspective. In *Energies* (Vol. 15, Issue 22, p. 8495). MDPI AG. https://doi.org/10.3390/en15228495