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Received: 23/07/2025

Revised: 08/10/2025

Revised: 16/12/2025

Accepted: 21/12/2025

Published: 22/12/2025

Academic Editor:

Dr. Alexandros Bartzokas-Tsiompras

Review Article

# Bibliometric Analysis of Decarbonization: Towards Energy Transition and Regional Resilience

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**Abstract:** Energy transition through decarbonization has become a cornerstone policy for a sustainable energy future. Enhancing regional resilience is a critical goal for the recovery of local systems from shocks and socio-economic disruptions caused by decarbonization policy. Investigating the consequences of energy transition in regions undergoing decarbonization with emphasis on regional resilience reveals a novel research area. The present study conducts a bibliometric analysis of 535 studies from Scopus published from 2010 to 2024, utilizing VOSviewer and R Studio's Biblioshiny software for visualization. The data demonstrate publication trends, geographic distribution, collaborations networks, and keyword clusters. A significant geographic inequality emerges. High-income economies dominate the discourse, while low-income countries contribute marginally. Furthermore, the co-occurrence analysis identifies six keyword clusters. Moreover, the thematic evolution depicts the field's transformation from an embryonic to a mature stage, strengthening core concepts of energy transition, decarbonization, and sustainability, while emerging specialized themes of renewable energy, just transition, and biomass. Finally, the analysis reveals a substantial gap: regional resilience remains underrepresented compared with decarbonization and energy transition, and constitutes a critical challenge for upcoming researchers.

**Keywords:** Energy transition; decarbonization; regional resilience; bibliometric analysis; Biblioshiny; VOSviewer

DOI: 10.48088/ejg.e.tos.16.2.419.435

ISSN: 1792-1341



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## 1. Introduction

Energy transition has been communicated as a counterweight to anthropogenic warming (Li, 2017) to meet the Paris Agreement 1.5°C target (UNFCCC, 2015). The transformation entails decarbonizing carbon-intensive energy systems (Delafield et al., 2021) to restore the balance between human activity and planetary limits (Li & Strachan, 2019). Practically, it describes the necessity to decrease greenhouse gas emissions (GHG) (IPCC, 2022) by shifting from fossil-based energy systems (coal, oil, and natural gas) to renewable energy systems (solar, wind, biofuel, and hydrogen) (Harichandan et al., 2022) to manage the environmental, economic, and social consequences of climate change (Delafield et al., 2021; Phillis et al., 2020). The COP26 Glasgow Climate Pact reimagined the global commitment to reducing GHG emissions by declaring phase-down of coal across the energy sector (Arora & Mishra, 2021; UNFCCC, 2021).

The academic interest has shifted from sustainability, a win-win scenario for present and future generations (Brundtland, 1987), to resilience. Despite the lack of consensus (Tsiapa et al., 2018), resilience has emerged as a desirable characteristic (Linnenluecke, 2017) investigating system behavior in the face of economic uncertainty, natural hazards, and climate catastrophes (Rogov & Rozenblat, 2018; Xue et al., 2018). Numerous economic, political, ecological, and social crises have transformed resilience into a crucial priority of societal, scientific, and political debates (Exner et al., 2016; Xue et al., 2018). The multidisciplinary nature of “resilience” (Exner et al., 2016) is interpreted through engineering, disaster management, socio-ecological, psychological and evolutionary perspectives (Giannakis & Bruggeman, 2017; Xue et al., 2018). Despite being critiqued as conceptually fuzzy (Gong & Hassink, 2017; Martin, 2018), resilience demonstrates a dynamic process, not just a static characteristic (Eraydin, 2016), acknowledging the significance of a system's adaptability (Xue et al., 2018) to further enhance vulnerability transformation and mitigate any adverse repercussions (Exner et al., 2016; Murua & Ferrero, 2019).

In this context, regional economic resilience has become particularly intense during periods of exogenous economic shocks (Xue et al., 2018), describing a regional economy's ability to respond to shocks spontaneously by absorbing disruptions (Rogov & Rozenblat, 2018), recovering,

restructuring, and restarting a novel development path following crises and epidemics (Giannakis & Papadas, 2021). Enhancing adaptability to any endogenous or exogenous stress is essential for achieving long-term regional economic development (Ala-Rämi et al., 2019). While sustainability is described as a normative concept oriented toward long-term goals, such as societal challenges to achieving sustainable development (Rogov & Rozenblat, 2018), resilience emphasizes entrepreneurial dynamics, socio-demographic aspects, and community interconnectedness (Urbančiková & Zgodavová, 2019). Nevertheless, different regions respond better to economic shocks. This is because a region's ability depends on a combination of regional components, such as the economic structure, local actors, institutional capacity, and extra-regional characteristics. Thus, metropolitan and urban areas tend to be the most resilient, while old industrial and rural regions exhibit a lower degree of resilience (Mai et al., 2021; Ženka et al., 2019).

The necessity to meet climate goals has led to a debate regarding energy policy decisions and their impact on regional economic development. In the context of securing the energy transition and addressing regional disparities, core issues such as energy affordability, equity, and public acceptance of policies have emerged. In concrete terms, the discussion refers to who will pay the bill for the energy transition on an individual level (householders) as well as the societal acceptability of the direct results on a regional level (communities), without jeopardizing the equality principle (Li et al., 2016). In this context, failure to ensure energy affordability and social acceptability implies the region's structural vulnerability to manage transition shocks and support regional resilience. However, the conceptual exploration of regional resilience related to energy transition is critical not to be approached merely theoretically (Exner et al., 2016). Decarbonization is interpreted as a pivotal structural transformation and a critical test of regional resilience across its economic, social, and institutional dimensions (Ala-Rämi et al., 2019). EU citizens recognize climate crisis and environmental degradation as key factors shaping the future of Europe (Bol et al., 2025). The implementation of the European Green Deal, which aims for climate neutrality by 2050, is supported by just transition mechanisms for regions directly affected by decarbonization shocks. However, each European region's transition is characterized by different combinations of resistance, adaptation, and transformation, indicating diverse levels of regional resilience (Cantoni & Claire Brisbois, 2024). Explicitly, regional transition toward sustainable development models necessitates effective institutional performance and coordinated policy action (Chatzitheodoridis et al., 2023; Chatzitheodoridis & Kontogeorgos, 2020) particularly in post-transition economies (Zafeiriou et al., 2023).

Specifically, regional resilience refers to the capacity of a geographically bounded system to withstand, absorb, adapt, and transform in response to external shocks and long-term structural changes (Martin, 2012). It synthesizes economic, social, and institutional dimensions to shape collective adaptive capacity, distinguishing itself from social resilience and economic resilience (Boschma, 2015; Martin & Sunley, 2017; Pike et al., 2010). Concretely, social resilience addresses community cohesion and adaptive capacity through collective action at the societal level, whereas economic resilience concentrates on economic structure and output recovery (Martin & Sunley, 2015).

The critical question is how regions historically reliant on coal-dependent economic activities overcome policy constraints, economic stressors, and manage to respond to the structural changes initiated by energy transition policies. While the energy transition remains a prominent issue in academic research, the examination of decarbonization's implications on regional resilience represents an emerging, yet underexplored, field of inquiry. The current study addresses this gap through a comprehensive bibliometric analysis, mapping the evolution of literature from 2010 to 2024. This analysis focuses specifically on the interconnections and critical linkages among energy transition, decarbonization and regional resilience and the spatial dimensions of the field. Three research questions (RQ) are formulated:

- RQ1: How has the publication output on energy transition, decarbonization, and regional resilience evolved between 2010 and 2024, and what is the geographic distribution of the most prolific actors (authors, countries, and sources) in this field?
- RQ2: What are the core thematic clusters in research on energy transition, decarbonization, and regional resilience, and how have their conceptual relationships evolved from 2010 to 2024?
- RQ3: What are the basic, motor, niche, and emerging themes indicated at the intersection of energy transition, decarbonization, and regional resilience, and how do they shape future research trajectories?

To shed light on these questions, the study synthesizes bibliometric technique, network visualization and thematic map analysis. To the authors' best knowledge, no prior bibliometric analysis has specifically explored the nexus of energy transition, decarbonization, and regional resilience. The study's novelty emerges from its focus on the combined analysis of the interrelationship between these three concepts, rather than examining each one separately. Emphasis is given to the interpretation of the findings through the lens of geographical inequalities in energy transition and socio-economic vulnerability of regions dependent on coal extraction. Considering that decarbonization extends beyond environmental issues, relating to multiple dimensions such as energy justice, regional development, economic transformation, and sustainability, the study is relevant to both environmental and social scientists. It is thus pertinent to academics and practitioners interested in energy transitions, regional development, energy and industry geography, and policy studies. Therefore, the findings aim to strengthen the theoretical foundation of the nexus and provide valuable insights for policymakers involved in mitigating the adverse impacts of decarbonization, shaping regional resilience strategies toward a just and sustainable transition. For this purpose, Section 2 discusses previous bibliometric studies and related literature background. Section 3 outlines the adopted methodology and the data collection process. Following the results in Section 4, Section 5 provides a critical discussion. Finally, Section 6 presents the conclusions and outlines recommendations for future research.

## 2. Related literature background

Decarbonization constitutes one of the critical strategies of global and European energy transition policy (European Commission, 2021; IEA, 2021) with multidimensional impacts on the carbon-dependent economies. Specifically, the closure of coal mines and power plants causes direct and indirect job losses, increasing out-migration, particularly among young people, thus eroding local social cohesion and reducing the coal-reliant region's capacity to resist (Healy & Barry, 2017). Addressing these complex challenges, to ensure just transition pathways, requires not only technological advancements, but also robust policy interventions, new governance arrangements, and active citizen engagement (Tampakis et al., 2017; Zafeiriou et al., 2022). The successful exit from the decarbonization shock depends on the region's capacity to attract alternative investments, stimulate economic diversification and workforce reskilling (Boschma, 2015).

Regions with strong institutional capacity can effectively utilize transition funding and implement innovative place-based policies, while those with weak governance struggle to access necessary resources (Grant et al., 2021). In this effort, the principles of energy citizenship and community energy are essential for a successful transformation toward a low-carbon society (Vanegas Cantarero, 2020). Consequently, policymakers must focus not only on regional economic benefits but also on achieving social well-being and environmental obligations at the local level (Bergman & Foxon, 2023). Beyond GHG limitation, the ongoing transition's goal should include economic growth through job creation, social

benefits such as energy security, energy equity, and environmental improvements (Obiora et al., 2024; Zafeiriou et al., 2018). For example, the community-ownership model within the energy transition implies the creation of new employment opportunities, increasing participants' income through land rentals, and encouraging entrepreneurship.

The holistic integration of economic, political, social, and communication parameters has emerged as a priority in the transition discourse (W. Chen et al., 2017; Diaconescu et al., 2024; Mansoor, 2025). According to Vanegas Cantarero (2020), especially in the post-COVID period, the energy transition's objectives for achieving sustainable development are expressed as goals related to economic growth, energy security, justice, social inclusion, and environmental sustainability. Acknowledging that the energy transition is not a one-size-fits-all procedure, knowledge transfer related to clean technology development and energy infrastructure among countries is crucial for pursuing justice and social inclusion (Harichandan et al., 2022). In this context, contemporary forms of international cooperation, known as the Just Energy Transition Partnerships (JETPs), have emerged to accelerate decarbonization and climate goals. Specifically, high-income countries provide financial support to developing and emerging economies, like South Africa, Indonesia, and Vietnam, to achieve a socially sustainable and just transition (Houston & Ruppel, 2022; Karg et al., 2025; Ordonez et al., 2024).

The selection of appropriate renewable energy strategies (Arabatzis et al., 2017) depends on the region's specific geological, morphological characteristics, and climate-induced vulnerabilities (Tampeki et al., 2023). For example, in regions facing water scarcity due to megadroughts, solar and wind technologies are mainly adopted in place of hydropower (Masip Macía et al., 2025). As the global energy system shifts from fossil fuels to electricity across power, heating, and transportation sectors (Bogdanov et al., 2021), the digital transition through smart grids and AI-driven optimization offers energy companies the ability to reduce operating costs and increase overall efficiency (Borowski, 2021). However, the green and digital transition's implications depend on regional heterogeneity and locally-based constraints, with the risk of separating regions into winners and losers (Kostarakos et al., 2025). In this context, the European Union underlines the necessity of place-based policies and spatial analysis for coal-reliant regions, directly affected by decarbonization shocks. In particular, the EU's Joint Research Centre (JRC) Energy and Industry Geography Lab<sup>1</sup> (EIGL) functions as a central hub, providing geographical data and maps related to energy, industry and infrastructure. The EU Energy Atlas is a crucial scientific tool that monitors the spatial impacts of the energy transition and decarbonization, ensuring their integration into policymaking.

Furthermore, as stated by Mukherjee et al. (2022), bibliometric analyses provide a starting point for future studies, enabling researchers to comprehend the research evolution (Mansoor, 2025), particularly in emerging domains, (Linnenluecke et al., 2020), and synthesize findings into a novel perspective (Post et al., 2020). Previous bibliometric studies have approached the energy transition topic from different perspectives. In this narrative, L. Wang et al. (2017) investigated the characteristics of low-carbon development transformation from 1995 to 2014. Likewise, Harichandan et al. (2022) provided a systematic analysis of the energy transition in the past four decades. They acknowledged that the energy transition narrative beyond a technological perspective should be enriched with robust strategies and policies, crucial for achieving climate and sustainable development goals, while ensuring cohesiveness (Harichandan et al., 2022). Furthermore, the clean energy transition has emerged as a main research topic on the energy agenda (Zhang et al., 2021). Specifically, Zhou et al. (2023) conducted a bibliometric review on the low-carbon transition pathways of energy systems, with a particular focus on the engineering management perspective. Whereas, Kaviti Musango (2024) focused on energy technology assessment in managing sustainable energy transitions. From different aspects, Xu et al. (2024) highlighted the importance of green finance policies in adopting new energy practices and generating financial profits, and Tabrizian et al. (2024) focused on the bibliometric analysis of energy governance. Nevertheless, none of these studies have addressed how regional resilience, as a territorially-bounded and multi-dimensional concept, emerges and interacts with decarbonization and energy transition. The present study systematically maps the discourse on decarbonization and regional resilience, revealing patterns in the evolution of this research domain.

### 3. Materials and Methods

The adopted methodology is similar to the protocols employed in studies in various research areas (Fahimnia et al., 2015; Fröhlich & Hassink, 2018; Harichandan et al., 2022; Khanra et al., 2020, 2021; Tandon et al., 2021; Graham et al., 2022; Guembe et al., 2025; Long et al., 2022; Sarfo et al., 2024; Su & Wang, 2022). Bibliometric analysis was selected due to its capacity to utilize unbiased citation databases (Shin & Perdue, 2019) and comprehensively uncover the intellectual structure of the topic without subjective bias (Xue et al., 2018). Figure 1 presents a schematic outline of the steps, the techniques, and their purposes, respectively. Specifically, the initial step was to formulate three research questions (RQ1, RQ2, RQ3). Next, data were collected from the Scopus database applying predefined criteria, including keywords, and a specified search period. The initial data then underwent a filtering process to retain only the most relevant and highest-quality publications for the final sample, deploying evaluative techniques (Paltaki et al., 2021). The study performed citation, co-authorship, and co-occurrence analyses. Finally, data visualization techniques such as the three-field plot, thematic evolution, and thematic mapping facilitated a comprehensive understanding and interpretation of the findings. Also, by deploying relational techniques, such as co-citation and co-author analyses, the study examines the relationships within the field and synthesizes the findings related to its knowledge foundation, structure, and trends (Shin & Perdue, 2019).

Specifically, the bibliometric analysis was conducted using a combination of VOSviewer and Biblioshiny (Aria & Cuccurullo, 2017). VOSviewer is a popular software that examines large databases and displays the findings using sophisticated settings (Jan van Eck & Waltman, 2017, 2021; Perianes-Rodriguez et al., 2016). Specifically, the graph illustrates the network, where larger nodes represent greater relevance, and thicker links manifest stronger linkages among nodes (Donthu et al., 2021). Hence, articles are represented as nodes, and citation combinations as edges (Fahimnia et al., 2015). In contrast, R Studio's Biblioshiny software provides graphic, thematic mapping, and a Three-field plot (Aria et al., 2020; Sarfo et al., 2024). To address RQ1, bibliographic coupling, co-occurrence, and citation analyses were employed, providing an overview of the leading authors, articles, countries, and sources. In reply to RQ2, co-authorship and co-citation analyses provide insights into the literature's thematic categories (Donthu et al., 2021; Tandon et al., 2021).

#### 3.1. Data collection

The appropriateness of the acquired data emerges as a key factor of success in the research and is crucial for fulfilling the stated purposes (Tandon et al., 2021). In the current study, a three-step procedure (Khanra et al., 2020) was implemented to identify appropriate literature data.

<sup>1</sup> [https://joint-research-centre.ec.europa.eu/scientific-tools-and-databases-0/energy-and-industry-geography-lab\\_en](https://joint-research-centre.ec.europa.eu/scientific-tools-and-databases-0/energy-and-industry-geography-lab_en)

- Data selection:** The present study utilized Scopus, as a comprehensive scientific database, to collect bibliographic information (Mongeon & Paul-Hus, 2016; Q. Wang & Waltman, 2016). The rationale for retrieving publications only from Scopus is multifaceted. In short, Scopus is perceived as the most extensive, representative, multidisciplinary database of peer-reviewed literature, widely popular, and easily accessible, providing publication metadata and citation metrics (Emich et al., 2020; Machado & Davim, 2022; Rogov & Rozenblat, 2018). Also, it provides fully cited reference information (Jan van Eck & Waltman, 2017; Olensky et al., 2016), and enables sophisticated searching combinations based on criteria, such as keywords, authors, and publication period (Wimbadi & Djalante, 2020). In light of the study's objective, Scopus provides the necessary methodological standards and data reliability for the analysis. Although various databases are available, such as Web of Science (WoS), Google Scholar, Crossref, and PubMed, there is a trend among researchers to retrieve data from only a single database to conduct bibliometric studies. Considering that the analysis focuses on the nexus of three core dimensions: energy transition, decarbonization, and regional resilience, relevant keywords were selected to comprehensively represent the multidimensional nature of the field. Specifically, the terms "energy transition", "energy efficiency", "low-carbon transition", and "just transition" were included to reflect technical, environmental, and social justice aspects of energy system transformation. Also, for the carbon reduction policy, the keywords "decarbonisation", "decarbonization", "coal phase-out", and "lignite phase-out" were chosen. The terms "regional resilience", "economic resilience", "social resilience", and "regional energy resilience" were also selected. These terms frequently appear in energy policy, sustainability science, and regional development in recent literature (Gong et al., 2020; Psycharis et al., 2022; Sovacool et al., 2020) and widely encountered in relevant policies and strategies, such as the European Green Deal, the Paris Agreement, the Just Transition Mechanism, and the COP21 Paris Agreement (Cantoni & Claire Brisbois, 2024; UNFCCC, 2021). The keywords "energy transition", "energy efficiency", "low-carbon transition", "just transition", "decarbonisation", "decarbonization", "coal phase-out", "lignite phase-out", "regional resilience", "economic resilience", "social resilience", "regional energy resilience", "sustainability", "sustainable development", "regional development" were chosen as viable and representative of the current analysis. Specifically, query strings of (TITLE-ABS-KEY("energy transition" OR "energy efficiency" OR "low-carbon transition" OR "just transition") AND TITLE-ABS-KEY("decarbonisation" OR "decarbonization" OR "coal phase-out" OR "lignite phase-out") AND TITLE-ABS-KEY("regional resilience" OR "economic resilience" OR "social resilience" OR "regional energy resilience" OR "sustainability" OR "sustainable development" OR "regional development")) from 2010 to 2024 has yielded an initial outcome of 977 documents.

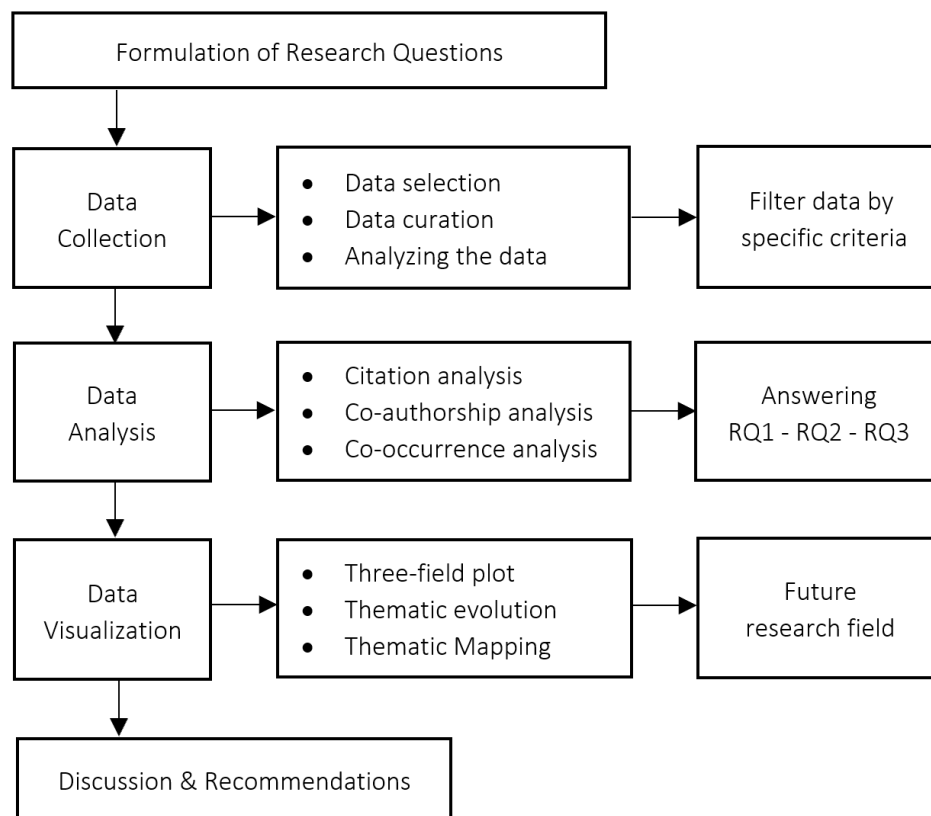


Figure 1. Schematic outline of the methodology.

- Data curation:** Figure 2 illustrates the PRISMA 2020 statement-based protocol, implemented to identify and screen the initial material (Page et al., 2021). The initial data (n=977) were limited by document type to only final articles in peer-reviewed journals. Hence, n=389 records from other categories were excluded. Also, n=7 articles were excluded due to the publication stage in press. During screening, articles in a non-English language (n=20) and source type of no journal (n=3) were excluded. At last, articles (n=23) from non-related subject areas were excluded. Therefore, n=535 articles were included, which is satisfactory for further bibliometric analysis (Donthu et al., 2021). During the selection and curation stages, the initial data underwent a rigorous cleaning and standardization process to ensure quality. Scopus's DOI-based deduplication and the Bibliometrix R package were employed

to eliminate duplicate records via Biblioshiny. Additionally, keyword harmonization was achieved using Biblioshiny to include terminological variations, e.g., "decarbonisation" (British) and "decarbonization" (American), ensuring data homogeneity.

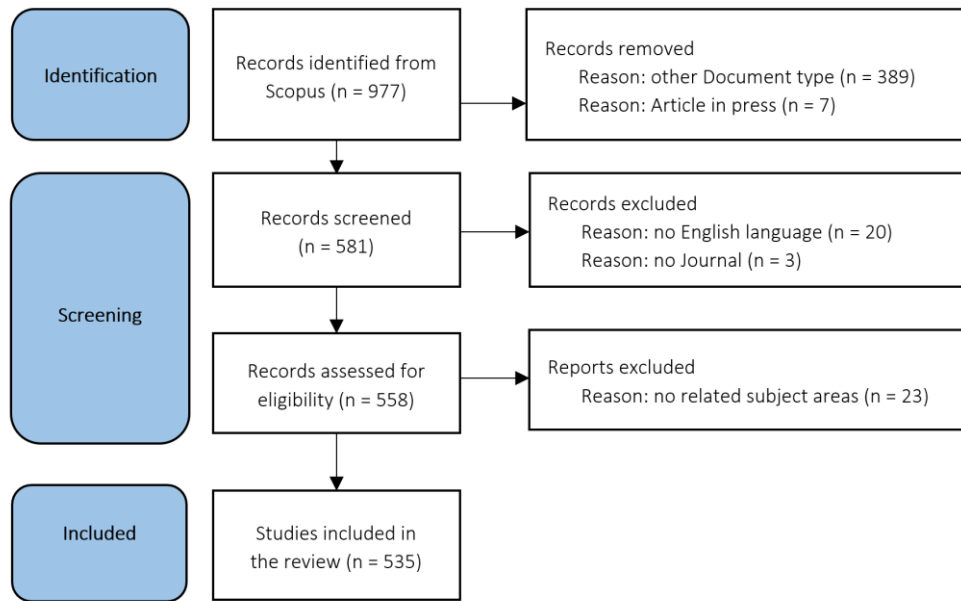


Figure 2. PRISMA 2020 flow diagram.

- Analysing the data: The final database includes 535 articles published from 226 academic journals between 2013 and 2024. These articles collectively contain 36.947 references, with an average citation per article of 22.64, and an article average age of 2.95 years. The publication trend reveals a substantial annual growth rate of 49.36% with the contribution of 1938 authors, located in 79 different countries, and an average of 3.98 co-authors per article. Finally, this database contains 55 single-authored articles, representing 53 individual authors of single-authored articles.

Figure 3 illustrates the progression of annual articles (blue line) and cumulative publications (orange line) within this field. Despite the lack of articles between 2010 and 2012 and the moderate activity from 2013 to 2016, academic engagement demonstrated a consistent upward trend beginning in 2018 and accelerating significantly between 2020 and 2024. Notably, the annual publications surged by 50% from 2023 to 2024, rising from 110 to 165 articles, respectively. This rapid growth suggests a transition period of crucial academic interest. Notably, the subsequent period (2021-2024) is considered a flourishing phase of research concentration in this specific field, marked by an average of 107.75 new publications annually.

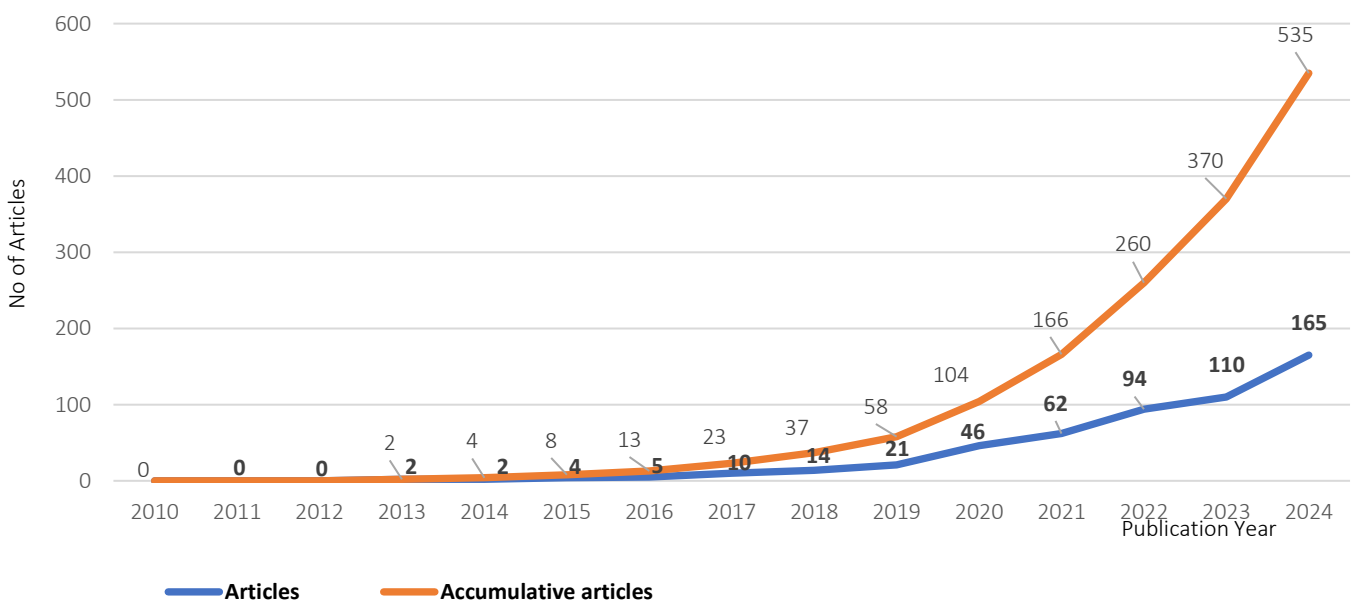


Figure 3. Timeline of annual production between 2010 and 2024.

#### 4. Results

The subsequent section focuses on bibliometric analysis and visualization. It provides information on the most influential authors, the collaborative network among authors, the academic communities, and their geographical distribution. The goal is to identify the field's foundation and evolution trend. To that purpose, the study employs techniques that combine past outcomes (co-citation analysis) and future projections (co-occurrence analysis) (Donthu et al., 2021).

##### 4.1. Citation analysis

Citation analysis is a quantitative evaluation of a given reference's citation counts from other publications, alongside an investigation into the connectivity created between pairs of nodes (articles) in a node network (Fahimnia et al., 2015). Also, it indicates a notion of influence and popularity for published articles by counting the number of citations, representing a measure of acceptance of publications (Tandon et al., 2021) and a degree of recognition (Khanra et al., 2020). Nonetheless, the significance of the top influential documents stems from their contribution to the introduction of updated words, which, as a result, encourages research participation in new areas (Y. Chen et al., 2022). Furthermore, citation analysis focuses on presenting the status of the field by highlighting the most significant contributors, underscoring the authors' research productivity.

Analysis of the data of the present study reveals that 9.35% of the articles were uncited. However, Table 1 presents the ten most globally cited articles, indicating the prominent influence and utility within the research area of decarbonization, energy transition, and regional resilience. Specifically, "Low-cost renewable electricity as the key driver of the global energy transition towards sustainability" (Bogdanov et al., 2021), published by Energy, shows 603 total citations, representing the current academic interest. The next two most influential articles are "Digitization, Digital Twins, Blockchain, and Industry 4.0 as Elements of Management Process in Enterprises in the Energy Sector" (Borowski, 2021) and "Total material requirement for the global energy transition to 2050: A focus on transport and electricity" (Watari et al., 2019). Despite its early publication year (2022), the article "Accelerating the energy transition to achieve carbon neutrality" (De La Peña et al., 2022) has underscored a high total citations per year (50.25%), highlighting that it is one of the most quickly recognized articles of the list.

**Table 1.** Top 10 Most Global Cited Articles.

Author	Title	TC	TC per Year	N.TC
BOGDANOV Dmitrii	"Low-cost renewable electricity as the key driver of the global energy transition towards sustainability" (Bogdanov et al., 2021) <a href="https://doi.org/10.1016/j.energy.2021.120467">https://doi.org/10.1016/j.energy.2021.120467</a>	603	120.60	13.77
BOROWSKI Piotr F.	"Digitization, Digital Twins, Blockchain, and Industry 4.0 as Elements of Management Process in Enterprises in the Energy Sector" (Borowski, 2021) <a href="https://doi.org/10.3390/en14071885">https://doi.org/10.3390/en14071885</a>	284	56.80	6.48
WATARI Takuma	"Total material requirement for the global energy transition to 2050: A focus on transport and electricity" (Watari et al., 2019) <a href="https://doi.org/10.1016/j.resconrec.2019.05.015">https://doi.org/10.1016/j.resconrec.2019.05.015</a>	235	33.57	4.37
DE LA PEÑA Lizette	"Accelerating the energy transition to achieve carbon neutrality" (De La Peña et al., 2022) <a href="https://doi.org/10.1016/j.resconrec.2021.105957">https://doi.org/10.1016/j.resconrec.2021.105957</a>	201	50.25	9.01
SOVACOOOL Benjamin K.	"The decarbonisation divide: Contextualizing landscapes of low-carbon exploitation and toxicity in Africa" (Sovacool et al., 2020) <a href="https://doi.org/10.1016/j.gloenvcha.2019.102028">https://doi.org/10.1016/j.gloenvcha.2019.102028</a>	200	33.33	5.58
BREYER Christian	"Solar photovoltaics demand for the global energy transition in the power sector" (Breyer et al., 2018) <a href="https://doi.org/10.1002/pip.2950">https://doi.org/10.1002/pip.2950</a>	173	21.63	3.76
SWILLING Mark	"Developmental States and Sustainability Transitions: Prospects of a Just Transition in South Africa" (Swilling et al., 2016) <a href="https://doi.org/10.1080/1523908X.2015.1107716">https://doi.org/10.1080/1523908X.2015.1107716</a>	166	16.60	3.20
EKINS Paul	"The costs and benefits of environmental sustainability" (Ekins & Zenghelis, 2021) <a href="https://doi.org/10.1007/s11625-021-00910-5">https://doi.org/10.1007/s11625-021-00910-5</a>	154	30.80	3.52
SOVACOOOL Benjamin K.	"Contestation, contingency, and justice in the Nordic low-carbon energy transition" (Sovacool, 2017) <a href="https://doi.org/10.1016/j.enpol.2016.12.045">https://doi.org/10.1016/j.enpol.2016.12.045</a>	145	16.11	3.16
GALÁN-MARTÍN Ángel	"Sustainability footprints of a renewable carbon transition for the petrochemical sector within planetary boundaries" (Galán-Martín et al., 2021) <a href="https://doi.org/10.1016/j.oneear.2021.04.001">https://doi.org/10.1016/j.oneear.2021.04.001</a>	143	28.60	3.26

Notes: TC = Total Citations, N.TC = Normalized Total Citations

Based on the authors' research productivity, Table 2 presents the ten most prolific authors with a significant contribution. A high level of authors' popularity implies engagement in contemporary research topics of global interest (Tandon et al., 2021). Sovacool B.K. has emerged as the most locally cited author with the highest performance in this field (TC=629) and an h-index of 5, having published 5 articles from the first publication in 2017 until 2024. Kinelski G., Rosenbloom D., and Zhou Y. also represent key contributors.

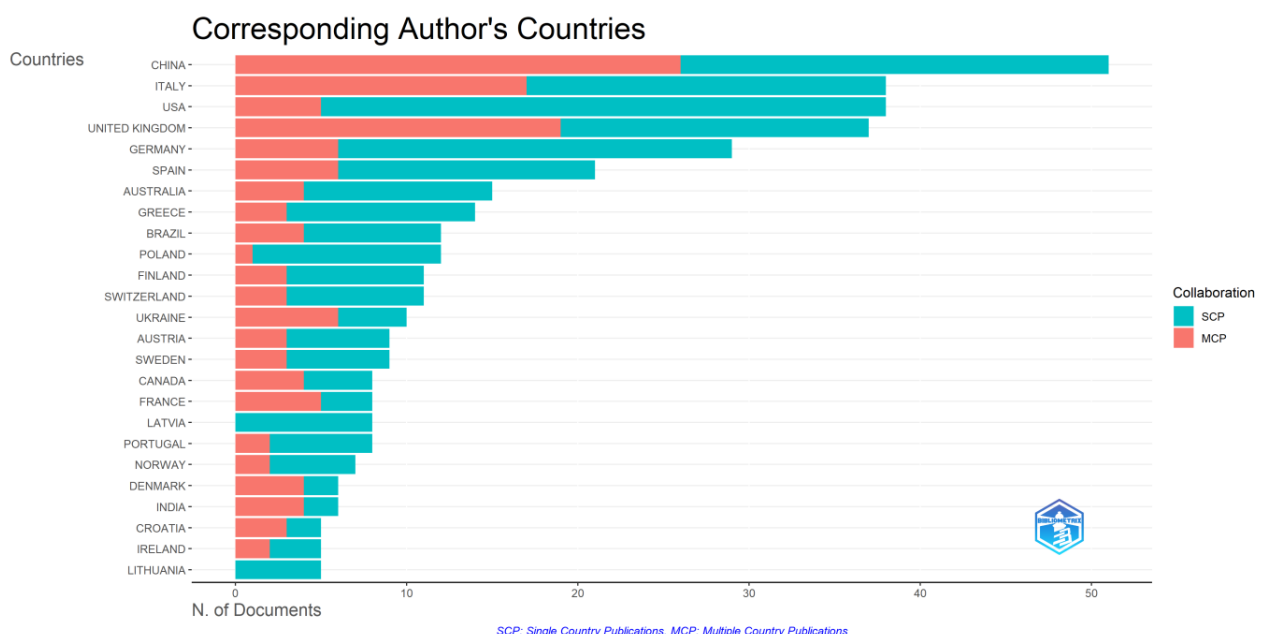
**Table 2.** Authors' publication productivity

Author	h_index	g_index	m_index	TC	NP	PY_start
Sovacool B.K.	5	5	0.556	629	5	2017
Kinelski G.	4	4	0.8	129	4	2021
Rosenbloom D.	4	4	0.5	221	4	2018
Zhou Y.	4	4	0.667	81	4	2020
Hearn A.X.	3	3	0.6	91	3	2021
Kurbatova T.	3	3	1	40	3	2023
Nikas A.	3	3	0.5	92	3	2020
Oei P-Y	3	3	0.429	76	3	2019
Pulselli R.M.	3	3	0.375	121	3	2018
Sotnyk I.	3	3	1	40	3	2023

**4.2. Geographic contribution and collaboration in the research field**

The research activity spans Europe (the UK, Italy, Germany, Spain, Greece, Poland, Finland, Switzerland, Ukraine, Austria, Sweden, France, Latvia, Portugal, Norway, Denmark, Ireland, Lithuania, and Croatia), Asia (China), North America (the USA, and Canada), South America (Brazil), and Australia. Leading contributions of significant research activity are recorded in the UK (78 articles), China (67), the USA (66), Italy (55), Germany (50), and Spain (41). Furthermore, Figure 4 presents the geographical origin of research publications, as determined by the corresponding author's country and affiliation from 2010 to 2024. Each bar represents the distribution between international and national research collaborations. Specifically, international research activity is measured by the number of Multiple-Country Publications (MCP) and illustrated in red, whereas domestic collaborations are displayed by the number of Single-Country Publications (SCP) in light blue.

Chinese authors hold a prominent position in research output, showing an almost equal distribution between domestic publications (SCP=26) and international collaboration (MCP=25). Italian authors record a slight preference for national research activity (SCP=21) compared to international (MCP=17). In contrast, authors from the USA demonstrate a significant preference for domestic research activity (SCP=33) compared to a low level of international research output (MCP=5), whereas UK authors maintain balanced research activity (SCP=18, MCP=19). Latvia and Lithuania exhibit a stronger domestic research with SCP=8 and 5, respectively, with no recorded MCP. Whereas France, Ukraine, Denmark, India, and the UK record high international research collaboration (MCP rates 62.5%, 60%, 66.7%, and 51.4%, respectively), indicating that the corresponding authors actively interact with global research networks.



**Figure 4.** Corresponding Authors' countries. Source: Authors, generated in Biblioshiny.

### 4.3. Co-authorship analysis and collaboration networks

Co-authorship analysis is defined by the number of co-authors in publications (Papadopoulou et al., 2021). It provides insights into the evolution of the domain by investigating synergy among authors, interactions, and geographical clustering (Donthu et al., 2021). Out of 1938 authors, only 18 meet the thresholds of a minimum of two documents per author and 150 citations. Hence, Figure 5 presents the density visualization of authors, illustrating their collaborative relationships based on their co-authored publications. The research networks are found in five distinct clusters among authors created with distinguishing features, interpreting the tendency for further intellectual development. The most prominent cluster includes Gulagi A., Agahhosseini A., Child M., Breyer C., Oyewo A.S., Farfan J., Bogdanov D., and Sadovskaia K.. These authors contribute to the field’s knowledge evolution since they have cultivated strong co-authorship synergies via substantial joint publications. Notably, authors of this core cluster belong among the top 10 with the highest local impact, underscoring each, the number of total citations (n=776) and a start year of 2018. Also, another cluster of strong co-authorship relationships includes Sovacool B.K., Hook A., Turnheim B., Brock A., and Martiskainen M.

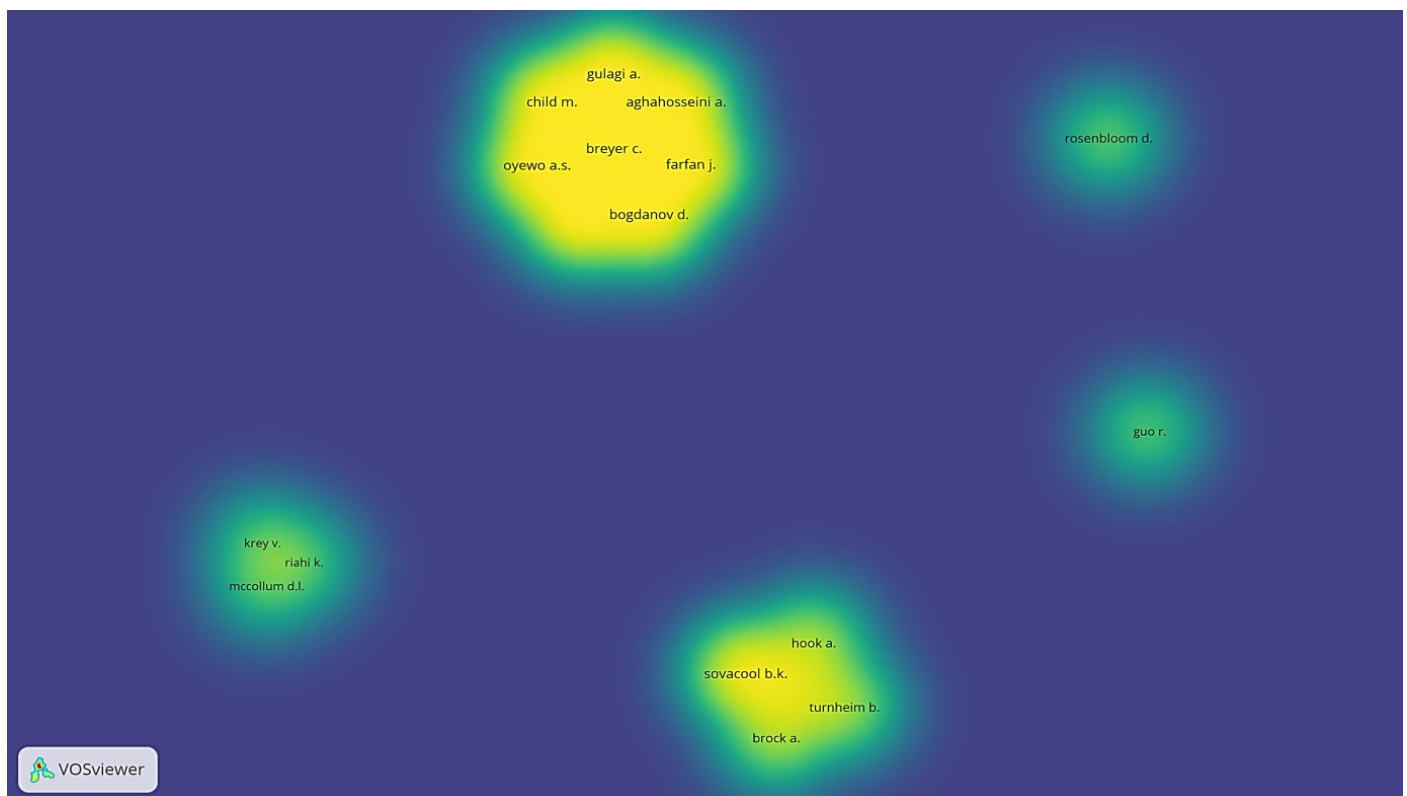


Figure 5. Density Visualization of Authors based on Co-authorship analysis.

Co-authorship analysis visualizes geographical research networks. The countries are distinguished by node size with dense linkages, implying that published articles in these countries receive the highest citations (Tandon et al., 2021). Hence, Figure 6 illustrates the network of countries derived from co-authorship analysis, identifying the most impactful international collaborations. From an initial database of 79 countries, only 34 meet the thresholds of 5 minimum articles and 100 minimum citations, representing a collaboration network divided into four clusters. The UK, China, the US, Italy, Germany, and Spain show a strong relationship in the co-authorship network. Also, emerging countries such as Poland, Greece, Switzerland, Finland, Austria, and Latvia are engaged in research activity. The lowest number of published articles is located in South America, Africa, and Central Asia. Finally, the data reveal that international co-authorships represent 33.83% of the total publications.

Figure 7 presents a three-field plot, known as the Sankey diagram. It provides insight into geopolitical and research dynamics, illustrating the crucial research topics corresponding to each country of article origin, and publication sources (Anastasiou et al., 2021). Each parameter contains twenty items. Countries with the highest number of publications are presented in the left column, key research topics in the middle, and publication sources on the right. Also, these parameters are interconnected by flows, with the bolder curves representing the most significant connections. Specifically, each country is linked to one or more research topics, with bold curves highlighting the countries exhibiting greater research activity in those topics. The flows continue from the research topics to the journals, illustrating the sources with the highest number of publications in that specific research output. Within this global academic engagement, researchers from the USA, China, the UK, Italy, Spain, and Germany represent the dominant contributors to the research output in this study’s field. The diagram reveals dominant research topics in *decarbonization/decarbonisation*, *energy transition*, *sustainability*, *energy efficiency*, *sustainable development*, *renewable energy*, and *climate change*. Furthermore, the plot identifies emerging themes including "just transition", "circular economy", "sustainable development goals", "sustainability transitions", "coal phase-out", as well as "green hydrogen", and "CO2 emissions", representing niche research areas. Finally, the ten most relevant sources contributing to the global knowledge dissemination include *Sustainability (Switzerland)* with 42 published articles, *Energies* (36 articles), *Energy Research and Social Science* (27), *Journal of Cleaner Production* (24), *Applied Energy* (22), *Energy Policy* (18), *Energy* (14), *Renewable and Sustainable Energy Reviews* (9), *Sustainable Cities and Society* (9), and *Energy Reports* (7) are the most productive journals.

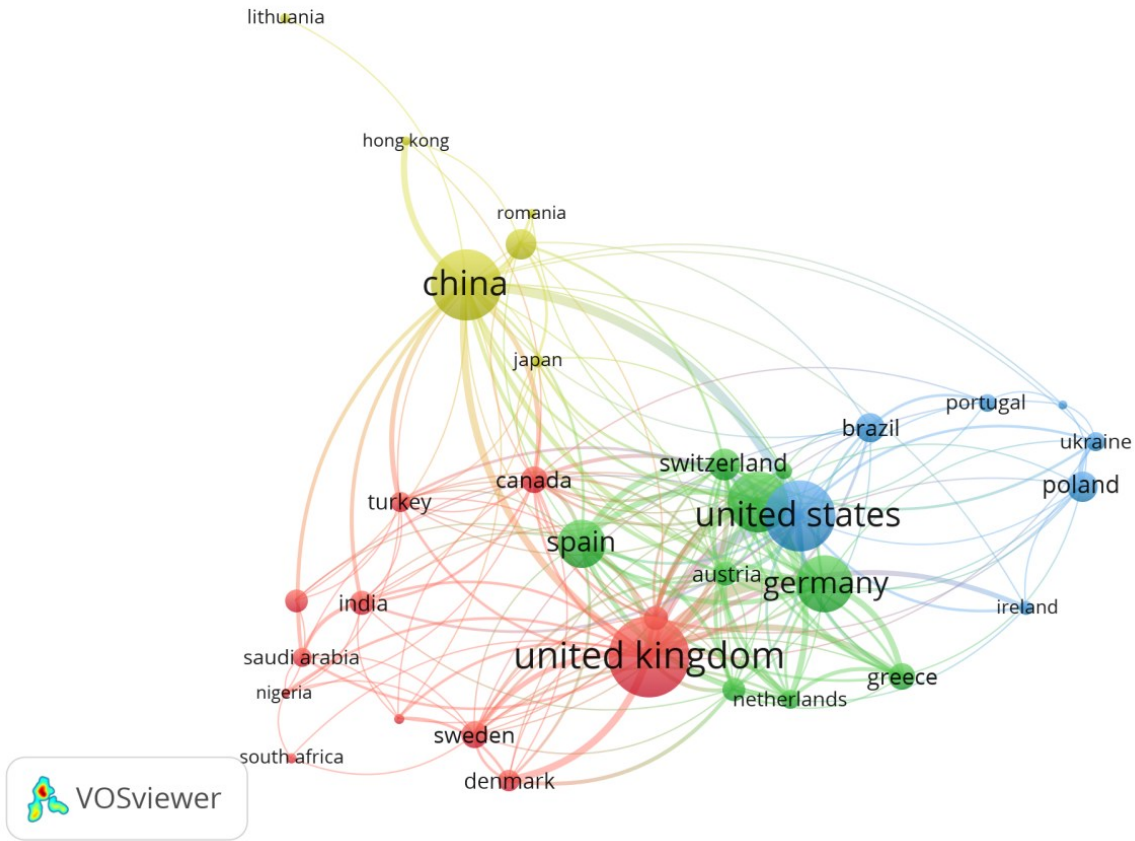


Figure 6. Network visualization of countries based on co-authorship analysis. Source: Authors, generated in VOSviewer

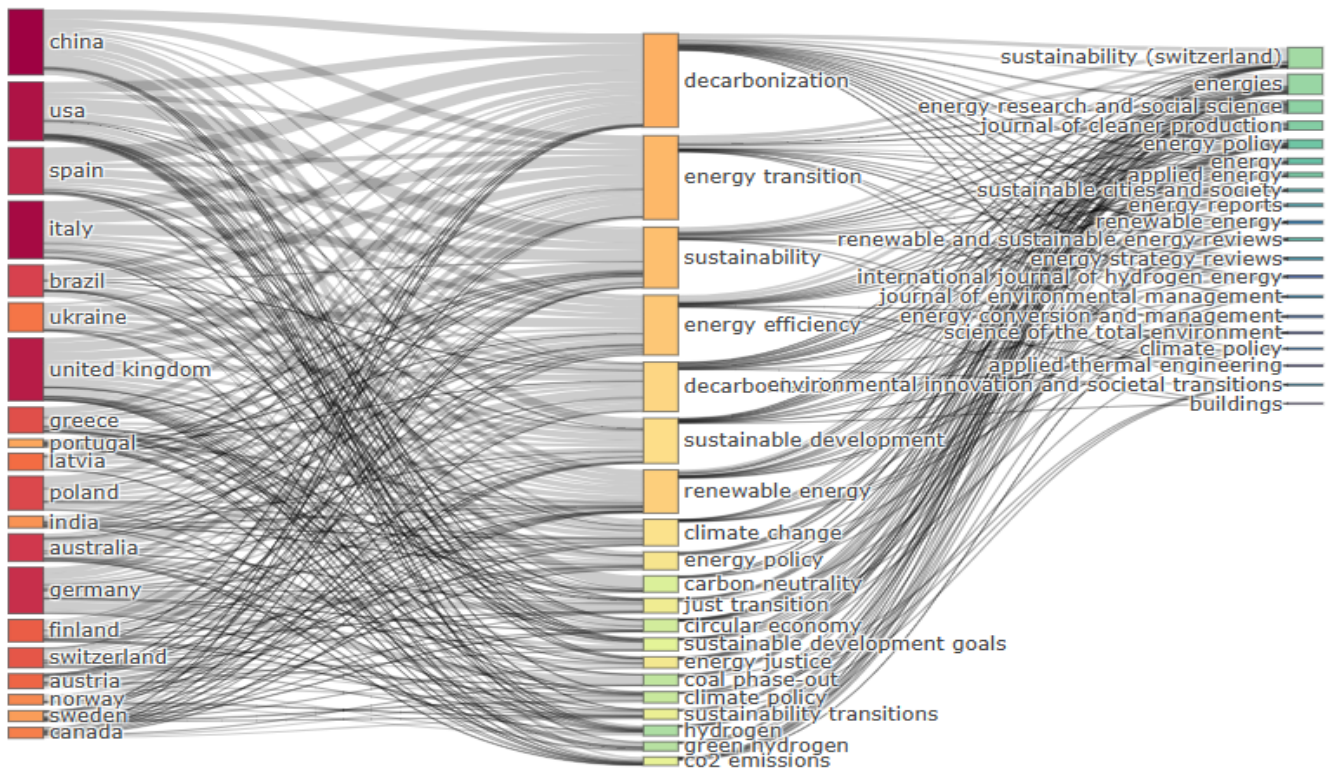


Figure 7. Three-field plot of research topics per country. Source: Authors, generated in Biblioshiny.

#### 4.4. Co-occurrence analysis

Co-occurrence or co-word analysis entails a quantitative research method to identify and visualize the relationships between keywords within a specific subject area. Keywords depict a figure (Khanra et al., 2020) since they describe the main characteristics of a publication, such as the scope, theory, methodology, recommendations, and limitations, and delve into its subject (Han et al., 2022). Based on the assumption that the greater the frequency of occurrence of a group of keywords, the stronger thematic relationship they form, the keywords can comprehend the core intellectual issue (Donthu et al., 2021) and forecast contemporary research trajectories in the field (Tandon et al., 2021). Nevertheless, the coherence of the co-occurrence analysis results is potentially sensitive to the choice of specific keywords, avoiding simple terms (Tandon et al., 2021). The network visualization is utilized to enrich the insights and graphically illustrate the thematic clusters with nodes representing keywords, and linkages between nodes indicating keywords' co-occurrence (Donthu et al., 2021). In this framework, the ten most relevant words with the highest number of occurrences are: *decarbonization* (98), *energy transition* (96), *sustainability* (68), *energy efficiency* (62), *renewable energy* (54), *sustainable development* (38), *climate change* (30), *energy policy* (19), and *energy justice* (17), and *just transition* (17). Figure 8 reveals six thematic clusters, formulated by the authors' keywords and depicted by different colors:

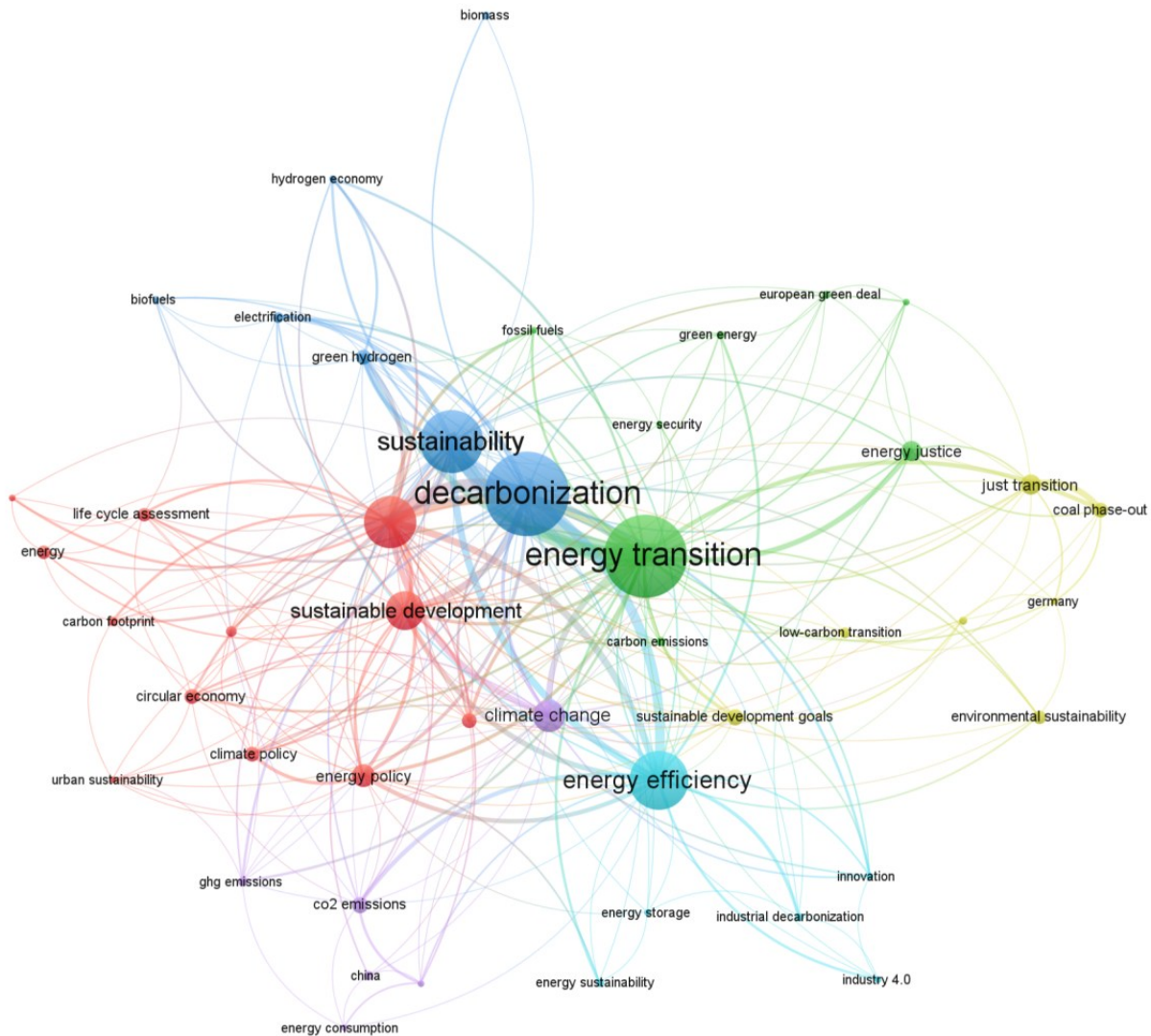
- **Green Cluster:** encompasses keywords of *energy transition*, *carbon emissions*, *coal*, *fossil fuels*, *energy justice*, *energy security*, *European Green Deal*, and *green economy*. This cluster represents the topic of "Energy transition and Energy Justice". With emphasis on energy transition, the challenge refers not only to mitigating carbon emissions and fostering a green economy, but also to safeguarding energy justice through robust policy (European Green Deal).
- **Blue Cluster:** includes the keywords *decarbonization*, *sustainability*, *biofuels*, *biomass*, *electrification*, *green hydrogen*, and *hydrogen economy*, representing the theme of "Decarbonization and Sustainability". This cluster examines how decarbonization is achieved through clean energy technologies (biofuels, biomass, electrification, and green hydrogen) with emphasis on sustainability.
- **Red Cluster:** is formulated by the keywords: *renewable energy*, *sustainable development*, *energy policy*, *carbon footprint*, *carbon neutrality*, *circular economy*, *climate change mitigation*, *energy*, *life cycle assessment*, *sustainability assessment*, and *urban sustainability*. This cluster is titled "Renewable Energy Goal and Sustainable Development", with a particular emphasis on the policy frameworks and their socio-economic and environmental implications.
- **Light Blue Cluster:** includes the keywords of *energy efficiency*, *energy storage*, *energy sustainability*, *industrial decarbonization*, *industry 4.0*, and *innovation*, reflecting topics related to "Energy Efficiency and Energy Sustainability". The crucial role of technological upgrading, particularly in energy storage solutions, in achieving industrial decarbonization, with the goal of energy sustainability, is highlighted.
- **Purple Cluster:** consists of *climate change*, *CO2 emissions*, *economic growth*, *energy consumption*, and *GHG emissions*, addressing the topics of "Climate Change and Economic Development" through the dimensions of environmental imperatives and growth needs.
- **Yellow Cluster:** is defined by *just transition*, *coal phase-out*, *environmental sustainability*, *low-carbon transition*, *sustainability transition*, and *sustainable development*, enclosing peripheral thematic topics of "Just transition, sustainable development, and environmental sustainability".

The visualization of the network highlights that the Blue, Green, and Red clusters are strongly interconnected and synthesize the conceptual core of the network. Specifically, the research focus is represented by the core terms "decarbonization" and "sustainability" (Blue cluster). These terms are highly connected to "energy transition" (Green cluster), displaying the broader objectives of "sustainable development" and "renewable energy" (Red cluster), and emphasizing their reliance on "energy policy" implementation. However, the Yellow cluster (just transition) is positioned as a peripheral and isolated cluster, while the Purple cluster (climate change) indicates a vital bridging role, connecting environmental issues with economic and policy dimensions. Furthermore, the Red and Purple clusters are strongly connected with the Green and the Light Blue clusters. These interconnections highlight that the Sustainable Development Goal (SDGs) is highly connected with climate change mitigation strategies. Additionally, a high network density exists between the Green cluster and the Yellow cluster. This suggests that research connecting "energy transition" and "coal-phase out" strategies significantly emphasizes themes of "energy justice" and "just transition". Furthermore, linkages between the peripheral themes of "biomass", "hydrogen economy", and "biofuels" and the social equity concerns of "just transition" and "coal phase-out" are totally absent. Another structural gap is observed between the Light Blue and Yellow clusters. It suggests that the current research has mainly focused on "innovation", "industrial decarbonization", and "energy sustainability", while topics of "just transition", "coal phase-out", and "environmental sustainability" goals remain underrepresented and isolated. Finally, the Light Blue cluster includes research bridging concepts. Terms of "energy efficiency", "innovation", and "energy sustainability" connect "energy policy", "sustainability", and "sustainable development" goals through "decarbonization" and "climate change".

#### 4.5. Thematic evolution and future research agenda

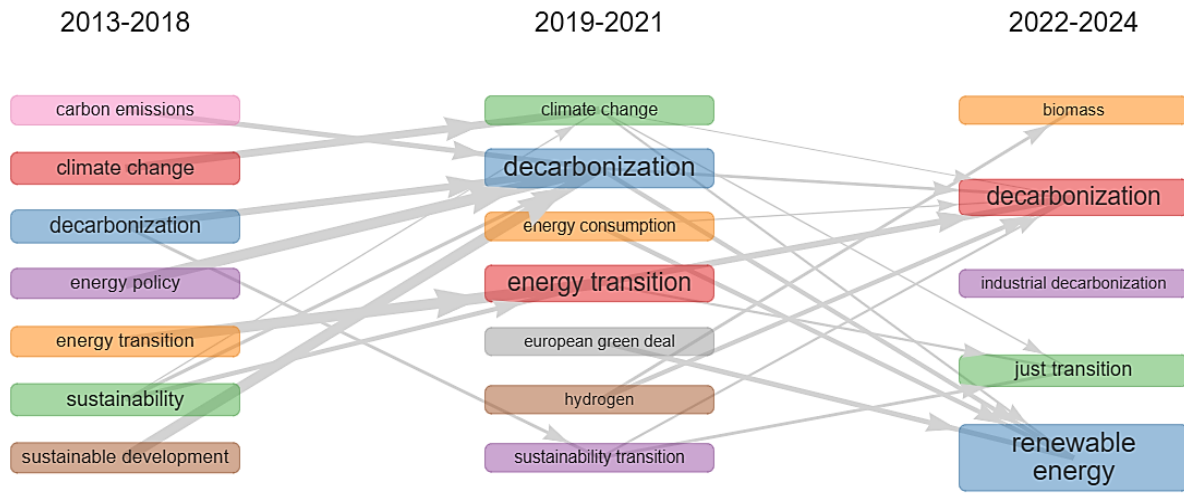
Figure 9.a illustrates the dynamic narrative of the research field from 2013 to 2024, revealing three distinct phases. The initial phase (2013-2018) represents the foundational period. It is characterized by limited publication output and foundational concepts, including carbon emissions, climate change, decarbonization, energy policy, energy transition, sustainability, and sustainable development. The visual representation of those terms indicates an early conceptualization stage. The second phase (2019-2021) demonstrates a substantial increase in scholarly output, with "energy transition" and "decarbonization" emerging as dominant concepts. In parallel, "climate change" remains an important research topic. This period also witnessed the introduction of specialized terms, such as the "European Green Deal", reflecting the European policy dimensions, "energy consumption", "sustainability transition", and novel technologies of "hydrogen", indicating growing thematic diversification. The third phase (2022-2024) exhibits exponential growth in publications, indicating an upward trajectory in academic discourse. The most prominent terms, "renewable energy" and "decarbonization", are consolidating as central research pillars. Hence, the research transformation and its specialization imply the reassignment of keywords and the emergence of new ones. This period is further distinguished by the emergence of socially-oriented concepts such as "just transition", alongside technological foci including "biomass" and "industrial decarbonization". In a nutshell, from the initial

“embryonic” stage, the research domain has been transformed into a more established and fruitful phase with dominant concepts during the last stage and potential avenues for further investigation.

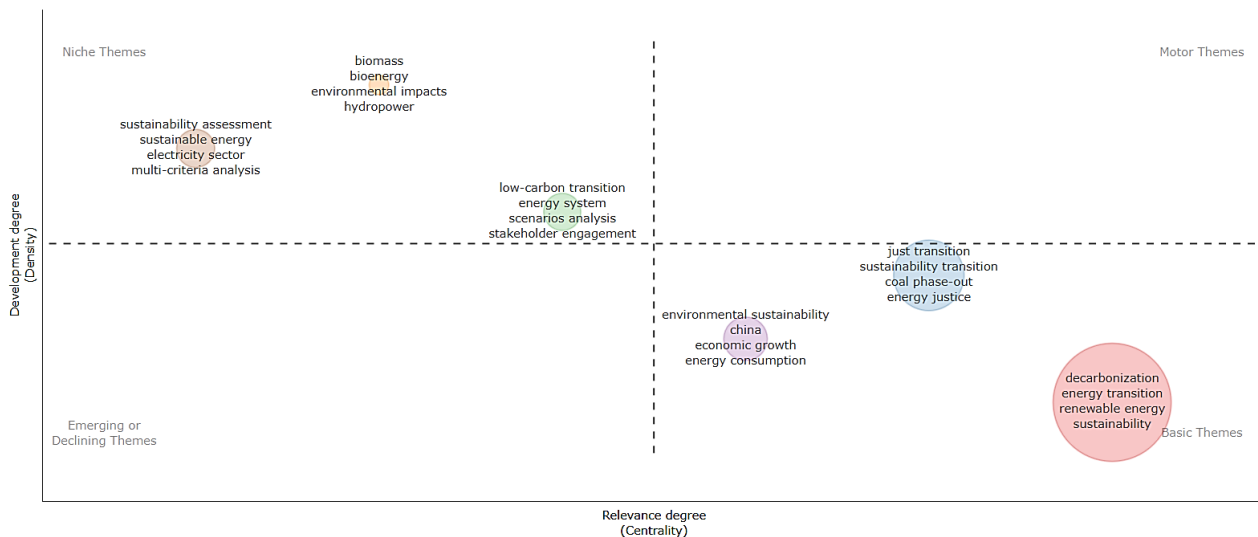


**Figure 8.** Network visualization of authors’ keywords.

In addition, Figure 9.b presents the research themes according to their centrality and density. The goal is to synthesize the structure of the research field and holistically identify potential future areas. The clusters are segmented as either *Basic Themes* (bottom right) or *Niche Themes* (top left), with *Motor Themes* (top right) and *Emerging or Declining Themes* (bottom left) absent. Notably, the analysis reveals an absence of *Motor Themes* as well as *Emerging or Declining Themes*. Specifically, the *Basic Themes* are illustrated through three clusters. The largest cluster in size includes the fundamental concepts of “decarbonization”, “energy transition”, “renewable energy”, and “sustainability”, distinguished by very high centrality and low development degree. These themes formulate the essential core of the specific research inquiry. Although they play a major role in the field, their low density suggests limited specialization and internal coherence. A second cluster of basic themes includes the concepts “just transition”, “sustainability transition”, “coal phase-out”, and “energy justice”. These themes are distinguished by a significant degree of density, indicating that they are central to current research interest and relatively well-developed internally. This cluster delves into the societal and ethical implications of energy transition, decarbonization, and sustainability, in the context of the management of social impacts derived from energy system transformations and coal phase-out, with emphasis on equity and justice. The third cluster within the *Basic Themes* includes “environmental sustainability”, “China”, “economic growth”, and “energy consumption”. These themes demonstrate high centrality and a relatively high density, focusing on the interrelation between environmental sustainability and economic development in the light of the management of energy consumption. The term “China” is likely to be interpreted as a significant case study of the research, highlighting the importance of specific national contexts and their policy implications in the global transition.



(a)



(b)

**Figure 9.** (a) Thematic evolution of the research field from 2013 to 2024; (b) Thematic map of the research field. Source: Authors, generated in Biblioshiny

In the upper left quadrant, *Niche Themes* compose three clusters of well-developed internal research within the research domain. While distinguished as specialized and technically focused research with strong internal coherence within their fields, the niche themes are characterized by a low degree of connection with the general research field of energy transition, decarbonization, and regional resilience. Specifically, one cluster includes renewable energy technologies of "biomass", "bioenergy", "hydropower", and "environmental impacts". A second cluster gathers the concepts "sustainability assessment", "sustainable energy", "electricity sector", and "multi-criteria analysis", representing specialized methodologies and analytical approaches related to the energy sector, sustainability evaluation, and energy systems. The third cluster contains the concepts "low-carbon transition", "energy system", "scenarios analysis", and "stakeholder engagement", distinguished by the highest centrality compared to the other two clusters. Notably, this cluster records themes of the lowest density degree, suggesting that, while being highly relevant to the conceptual field, their internal development and interconnectedness within a conceptual framework are still evolving. These topics can also be characterized as emerging, as they did not manage to maximize specialization and centrality levels. The absence of Motor Themes is interpreted as a result of the continuous evolution of the field. The research is mainly based on fundamental and diffuse concepts. Nevertheless, the important sub-fields have not yet fully matured into separate "motor force" clusters. Hence, the dynamic development enhances the core concepts as Basic Themes, avoiding their transformation into "mature motor themes".

### 5. Discussion

The present study uncovers unexpected patterns regarding how decarbonization intersects with regional resilience. An initial finding is the geographic inequality in research output expressed by the dominance of authors from high-income economies, particularly Western European countries, China, and the USA. On the contrary, low-income countries with high coal dependency and significant exposure to decarbonization impacts contribute disproportionately to the discourse. There is a dilemma about whose experiences shape energy transition policies. The

underrepresentation of coal-dependent regions risks producing a unilateral narrative that privileges high-income country experiences, potentially undermining the validity of transition policies applied globally. This can be attributed to structural constraints in research funding, infrastructure gaps, and restricted journal access. This asymmetry raises both scientific and ethical concerns. Since economically advanced countries have established themselves as research hubs through dense co-authorship networks, research imbalance is evident, producing epistemological consequences. The marginalization of coal-dependent developing regions, such as India, Indonesia, and South Africa, from the academic discourse means that their unique socio-economic patterns, governance challenges, and community experiences remain invisible in the theoretical frameworks and policy recommendations. Addressing this research injustice requires deliberate prioritization of case studies from low and middle-income regions. Such an approach ensures that discourse on regional resilience and energy transition through decarbonization incorporates diverse socio-economic contexts, preventing policy decisions based exclusively on high-income country experiences. However, the findings indicate a notable underrepresentation of high-capacity countries, such as France and the Netherlands. This observation reflects that the selected keywords do not fully capture relevant contributions or different national research priorities.

Furthermore, the analysis reveals distinctive trends in field development. Publications emerged from 2013 onward, indicating an opportunity to capture valuable insight into the early-stage field evolution. The period 2022-2024 exhibits an exponential increase in publications, reflecting intensified attention from researchers. This acceleration can be attributed to the field's novelty and contemporary nature as an extremely dynamic and timely issue. Chronologically, the most cited publications appeared between 2016 and 2022, a period of increased academic engagement with climate change, geopolitical instability, and energy transition objectives. Finally, the observed trajectory suggests continued growth in publication volume over the coming years, indicating sustained momentum in this research domain.

Six pivotal thematic clusters represent a core-periphery structure constituting a complex causal system with distinct pathways. This causal architecture stems from "renewable energy" targets (red cluster), driven by global concerns about "climate change" mitigation through reduced "CO<sub>2</sub> emissions" and "energy consumption" (purple cluster). Achievement of these objectives necessitates "energy transition" policies (green cluster) that incorporate social dimensions such as "energy justice" (green cluster), "energy efficiency" (light blue cluster), and "just transition" (yellow cluster). Notably, "decarbonization" (blue cluster) emerges as a strategic pathway toward "energy transition" (green cluster), exhibiting strong co-occurrence that cascades into "sustainability" (blue cluster) and "sustainable development" (red cluster) dimensions. However, this transition trajectory presents critical challenges for coal-dependent regional economies confronting "low-carbon transition" (yellow cluster) and "coal phase-out" strategies (yellow cluster). The vulnerability of these regions to decarbonization policies varies considerably: higher dependence on fossil fuels (green cluster) correlates with greater exposure to economic contraction, fiscal stress, and labor market disruption.

However, the findings demonstrate causal linkages between enhanced "sustainability" (blue cluster) in regions where "decarbonization" leverages alternative technologies, including green "hydrogen", "biomass", and "biofuels". The connection between blue and light blue clusters is evident. It further suggests how industrial regions pursuing energy efficiency and industrial decarbonization through innovation, digital transformation, and Industry 4.0 advance simultaneously toward decarbonization and sustainability. In addition, the network visualization represents robust connectivity between "energy transition" and "energy justice" (green cluster), alongside "just transition" and "coal phase-out" (yellow cluster). This configuration reflects a shift of research from techno-economic analyses of energy transition toward integration of climate policy with social inequalities and justice concerns. Research addresses distributive justice (energy justice) and social equity considerations (just transition), likely influenced by European Union policy frameworks such as the Just Transition Mechanism, demonstrating the field's progression and maturation. Nevertheless, these findings do not clarify why certain regions demonstrate superior effectiveness in achieving energy transition and sustainability.

The geographic reference revealed in keyword analysis, dominated by "Germany" (yellow cluster) and "China" (purple cluster), highlights the field's spatial limitations. This limitation implies that research still lags in the development of spatial analytical frameworks and comparative place-based analysis. In short, Germany's co-occurrence with "just transition", "coal phase-out", and "sustainable development goals" (yellow cluster) reflects its leadership in just transition policy and environmental sustainability strategy. Also, China's association with "CO<sub>2</sub> emissions" and "energy consumption" (purple cluster) emphasizes research focus on its position as one of the world's largest emitters and its climate change implications. The absence of other countries in keyword networks signals risks of unilateral research focus. This geographic imbalance marginalizes or entirely excludes diverse regional experiences with energy transition and decarbonization, undermining the theoretical framework's applicability across broader geographic contexts. The field urgently requires the development of spatial analytical frameworks, prioritizing comparative place-based analyses. Finally, limited connectivity between "hydrogen economy" and "biomass" (blue cluster) with other keywords indicates that in the current research, "hydrogen" is examined in isolation rather than integrated with socioeconomic transition dimensions, representing a significant research gap.

The thematic evolution reflects both the research's interest as well as the response to contemporary political imperatives, particularly set by the European Green Deal and the Just Transition. Furthermore, the analysis reveals the centrality of "decarbonization" and "renewable energy", functioning as absorptive hubs that integrate adjacent and multidisciplinary concepts (*climate change, energy consumption, energy transition, sustainability transition, and the European Green Deal*). Despite the growth of the research output, there are no Motor Themes in the thematic map. This absence is a significant finding, explained by the multidisciplinary characteristics of the theoretical background. Decarbonization includes concepts from environmental, economics, engineering, and social sciences, preventing the formation of dominant and dense thematic clusters. Notably, the absence of Motor Themes reflects the research's limited capacity to bridge adjacent thematic clusters and strengthen the theoretical advancement of the domain. Despite being included in the initial search string, "regional resilience" does not appear in either the keyword clusters or the thematic map. This critical absence has revealed that "regional resilience" has not established meaningful connections with the "energy transition" or "decarbonization". This underrepresentation highlights a crucial conceptual disconnection among the three terms, attributed to terminological fragmentation. Specifically, researchers use synonymous or alternative terms such as economic resilience, local resilience, socio-spatial resilience, and adaptive capacity.

## 6. Conclusion

The analysis reveals a paradox: while "regional resilience" was included as one of the main concepts in research design, it remains invisible in decarbonization discourse. Notably, literature has not sufficiently integrated the spatial and social dimensions of resilience into energy transition and decarbonization goals. Hence, future research should develop regional resilience within decarbonization contexts. The priority emerges from integrating specialized niche themes with sustainability assessments of biomass, bioenergy, and hydropower, linking environmental impacts with

regional adaptive capacity. Also, a second research priority focuses on cross-national case studies and comparative empirical analyses of emerging economies, with consideration of spatial heterogeneity. In this context, research explores new trajectories in the decarbonization agenda, with particular emphasis on structural transformation and resilience enhancement in regions undergoing energy transition. This should be achieved by evaluating the socioeconomic effects on local communities and policy recommendations that mitigate adverse impacts, ensure energy justice, and strengthen regional resilience. Furthermore, it is crucial to focus on “just transition” beyond the limited political perspective, unfolding the inherently multidimensional nature of the concept.

Since the present study is one of the initial bibliometric analyses, a detailed discussion of similarities and differences with prior research remains limited. Nonetheless, the study acknowledges several methodological constraints, which offer fruitful avenues for future research. Reliance on a single database (Scopus) and specific search keywords introduces thematic and geographical biases, constraining the comprehensiveness of the findings. Upcoming researchers probably address this by employing additional databases, such as Web of Science (WoS), to enhance the literature base and enable comparative analyses of indexed keywords and metadata quality assessments. Furthermore, an empirical comparison of metadata quality between Scopus and WoS, combined with cross-analyses involving altmetrics, would provide valuable methodological insights. While this study focuses on the early stage of the field's development and provides network visualizations and thematic evaluation, it also faces data limitations regarding connected datasets, which restricted the depth of the network analysis. In this light, apart from the visual network representations, research provides a comprehensive quantitative perspective of the network analysis metrics, including link strength, centrality measures, modularity scores, and dynamic co-citation analysis. Also, detailed content analyses of identified thematic clusters represent another potential avenue for methodological advancement. Finally, expanding the research into a systematic review combined with comprehensive modeling of decarbonization's implications and empirical studies will be crucial for new resilient pathways to achieve global energy transition goals.

**Funding:** This research received no external funding.

**Data Availability Statement:** Research data are available upon request.

**Conflicts of Interest:** The authors declare no conflict of interest.

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