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Global Research Dynamics On Weather Derivatives: A Bibliometric Analysis Of Climate, Temperature, And Pricing Models (1957–2025)

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Abstract:
This study presents a comprehensive bibliometric analysis of global research on weather derivatives, with a focus on climate, temperature-based risk, and pricing models spanning from 1957 to 2025. The research aims to explore the intellectual structure and thematic evolution of the field, investigate patterns of author collaboration and international research networks, and assess the development of pricing models in response to increasing climate variability. It seeks to answer how the volume and thematic focus of scientific publications on weather derivatives have evolved over time, which keywords, authors, and journals have been most influential, and how international collaborations have shaped the dissemination and impact of this research area. Although weather derivatives have gained importance as financial instruments for hedging climate-related risks, there remains a significant gap in understanding their interdisciplinary development from a bibliometric perspective. Using performance analysis and science mapping through the Bibliometrix R-package, this study analyzes 778 documents from 457 sources, revealing an annual growth rate of 5.65%, an average of 27.75 citations per document, and a 26.99% international co-authorship rate. These findings highlight the expanding yet fragmented nature of research in this domain and provide insights for future studies to refine pricing methodologies, strengthen policy integration, and encourage cross-disciplinary collaboration.
KeyWords: *Weather Derivatives, Bibliometric Analysis, Climate Risk, Temperature-Based Pricing, Scientific Collaboration*

1.INTRODUCTION :

In recent decades, the intensification of climate variability has heightened the need for innovative financial instruments to manage weather-related risks. Among these, weather derivatives have emerged as key tools allowing businesses—particularly in agriculture, energy, and insurance sectors—to hedge against financial losses arising from adverse weather conditions (Jewson & Brix, 2005). These contracts, which derive their value from weather indices such as temperature, rainfall, or snowfall, are increasingly viewed as viable alternatives to traditional insurance, especially as climate change renders historical risk models inadequate.

Despite their growing relevance, the academic exploration of weather derivatives remains fragmented across disciplines, including finance, meteorology, climatology, and risk management. While several studies have examined pricing models such as burn analysis, Monte Carlo simulations, and actuarial methods, others have explored regulatory barriers, risk quantification techniques, and the integration of weather derivatives into broader sustainable finance frameworks (Dischel, 2002; Cao & Wei, 2004). However, there remains a significant gap in the bibliometric understanding of how this field has developed intellectually and collaboratively over time.

To address this gap, the present study conducts a bibliometric analysis of 778 scholarly documents published across 457 sources from 1957 to 2025. The dataset reveals an annual publication growth rate of 5.65%, with an average of 27.75 citations per document, and an international co-authorship rate of 26.99%, indicating both increasing academic interest and growing international collaboration in the field. Using the Bibliometrix R-package, this research aims to map the intellectual evolution of global research on weather derivatives, with a focus on climate and temperature-based pricing models.

This study contributes to the literature by pursuing three objectives: exploring global publication trends and thematic evolution, identifying the most influential journals, authors, and keywords, and examining the role of international collaboration in knowledge production. The results offer valuable insights into the interdisciplinary nature of this field and provide a foundation for future research aimed at refining pricing methodologies and enhancing policy integration in the context of climate risk management.

2.LITERATURE REVIEW

The emergence of weather derivatives in the late 1990s marked a significant shift in how businesses and financial institutions manage weather-induced risks. These instruments, priced based on weather indices such as temperature, precipitation, or wind speed, provide an alternative to traditional insurance mechanisms (Jewson & Brix, 2005). Early theoretical contributions focused on pricing models using stochastic processes and actuarial techniques (Brody, Syroka, & Zervos, 2002; Alaton, Djehiche, & Stillberger, 2002). Over time, the relevance of these models has grown due to increased climate variability and the financial exposure of weather-sensitive sectors like agriculture and energy (Turvey, 2001).

Despite this progress, the field has developed in a fragmented and multidisciplinary manner. According to the bibliometric dataset analyzed in this study, a total of 778 documents from 457 sources were published between 1957 and 2025, indicating the longevity and gradual maturation of the field. The annual growth rate of publications is 5.65%, reflecting a steady increase in scholarly attention. However, the average document age of 10.3 years suggests that much of the impactful literature may not be recent, and there is room for updating methods and focus areas in light of emerging climate risks and financial innovation (Cao & Wei, 2004; Dischel, 2002).

An important dimension of this bibliometric profile is scientific collaboration. The dataset shows 3,175 authors, with an average of 4.67 co-authors per document, and 26.99% international co-authorship, signaling moderate but meaningful global academic engagement. Still, only 61 single-authored documents and 55 unique authors of single-authored works exist, showing that collaboration, though present, is uneven. Prior studies have noted that while pricing and application models are widely researched, less attention has been given to policy integration, international regulation, and interdisciplinary coordination (Mete, 2019; Anderson & Chu, 2011). The 9,000+ Keywords Plus (ID) and 2,631 author keywords suggest thematic diversity, but possibly at the cost of conceptual coherence in the field.

The use of bibliometric methods has been instrumental in evaluating such fragmented academic landscapes. Tools like the Bibliometrix R-package have helped researchers visualize publication trends, collaboration networks, and influential keywords (Aria & Cuccurullo, 2017). In the present study, the relatively high average citation rate of 27.75 per document underscores the significance of key contributions, even in a scattered field. Recent bibliometric reviews in related domains, such as climate finance, show similar patterns—moderate international collaboration, strong early theoretical development, and emerging interest in sustainability and adaptation (Alexopoulos & Kounetas, 2020; Pereira, Quintana, & Guedes, 2021). Therefore, this bibliometric assessment not only maps the historical evolution of weather derivatives but also calls for renewed efforts toward methodological integration and policy-relevant research.

3. METHODOLOGY

This study adopts a bibliometric approach to examine the global research trends, thematic evolution, and collaborative structures within the field of weather derivatives, particularly focusing on climate, temperature-based risks, and pricing models from 1957 to 2025. Bibliometric analysis is a quantitative technique used to assess scientific publications through indicators such as publication volume, citation analysis, co-authorship patterns, and keyword trends. The methodology combines performance analysis and science mapping to provide a comprehensive overview of the research landscape.

3.1 Data Source and Collection

The bibliographic data for this study were retrieved from the Scopus database, which is one of the largest and most reliable abstract and citation databases for peer-reviewed literature across disciplines. A structured search query was constructed using keywords related to “weather derivatives,” “climate risk,” “temperature-based pricing,” and related terms. The timespan was restricted from 1957 to 2025 to capture the full historical development of the field and account for forecasted or in-press works. After applying

inclusion criteria such as English language and document type (journal articles, books, and conference papers), a final dataset of 778 documents from 457 distinct sources was compiled.

3.2 Analytical Tool and Procedure

The collected metadata were exported in BibTeX format and analyzed using the Bibliometrix package (Aria & Cuccurullo, 2017) in the R Studio environment. Bibliometrix is an open-source R tool designed for comprehensive science mapping and bibliometric analysis. The main analytical steps included:

- Descriptive performance analysis: To evaluate annual publication trends, citation metrics, average document age, and growth rate.
- Source and author metrics: To identify the most prolific journals, authors, and institutions.
- Keyword analysis: To trace thematic evolution and identify emerging topics through co-occurrence analysis.
- Collaboration patterns: To assess single vs. multiple authorship, co-authors per document, and international collaboration rates.

3.3 Bibliometric Indicators

The analysis focused on key bibliometric indicators derived from the data, including:

- Annual Growth Rate: 5.65%
- Average Citations per Document: 27.75
- Document Average Age: 10.3 years
- International Co-authorship Rate: 26.99%
- Total Authors: 3,175 with 61 single-authored documents
- Keywords Plus (ID): 8,996 and Author's Keywords (DE): 2,631

These indicators were used to interpret the productivity, impact, and collaboration dynamics in the field. The use of both Keywords Plus and Author Keywords enabled a deeper understanding of the conceptual structure and content focus of the literature.

4. RESULTS AND DISCUSSION:

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	1957:2025
Sources (Journals, Books, etc)	457
Documents	778
Annual Growth Rate %	5.65
Document Average Age	10.3
Average citations per doc	27.75
References	0
DOCUMENT CONTENTS	
Keywords Plus (ID)	8996
Author's Keywords (DE)	2631
AUTHORS	
Authors	3175
Authors of single-authored docs	55
AUTHORS COLLABORATION	
Single-authored docs	61
Co-Authors per Doc	4.67
International co-authorships %	26.99
DOCUMENT TYPES	
article	771
article article	7

Table 1: Data Description

4.1 Descriptive Analysis of the Bibliometric Dataset

4.1.1. Scope and Publication Trends

The dataset covers publications from 1957 to 2025, reflecting a broad historical range and suggesting long-term academic interest in the topic. While this wide timespan supports a comprehensive analysis, earlier studies may be underrepresented due to database coverage limitations and non-English language barriers.

The annual growth rate of 5.65% indicates a steadily expanding field. This consistent growth points to increasing scholarly engagement. Further analysis of year-wise publication trends can reveal periods of notable expansion or decline, offering insights into the field's evolution.

A total of 778 documents are included, indicating a moderate research volume. Compared to larger disciplines, this may reflect a specialized or emerging area. Publications are distributed across 457 different sources, such as journals, books, and conference proceedings, signaling interdisciplinary interest and diverse publication outlets. This wide spread strengthens the field's credibility and global appeal.

The average age of documents is 10.3 years, suggesting that the literature is fairly current and active, rather than dominated by outdated foundational works. This is favorable for a dynamic research environment that incorporates recent developments.

Each document receives an average of 27.75 citations, pointing to a moderate impact. While this number may seem strong, citation behavior is highly field-dependent. Review articles tend to attract more citations than empirical papers, and citation practices vary across disciplines. Nonetheless, this metric implies meaningful academic engagement.

4.1.2. Authorship Patterns and Collaboration

The corpus includes work by 3175 authors, confirming a large and active research community. Only 55 authors produced 61 single-authored papers, emphasizing that collaborative work is the norm in this field. This trend is common in mature disciplines where team-based research is standard.

An average of 4.67 co-authors per document further supports the field's collaborative nature. Importantly, 26.99% of publications involved international co-authorship, highlighting a global research network. This level of cross-border collaboration reflects the topic's international relevance and openness to diverse perspectives.

4.1.3. Document Types and Thematic Focus

Regarding thematic content, the dataset includes 8996 Keywords Plus and 2631 Author Keywords. Keywords Plus are generated from cited references, offering a broader sense of associated themes, while Author Keywords provide direct insight into the authors' intended focus. Comparing these two can help identify terminological trends, emerging research areas, and gaps in self-identified vs. indexed content.

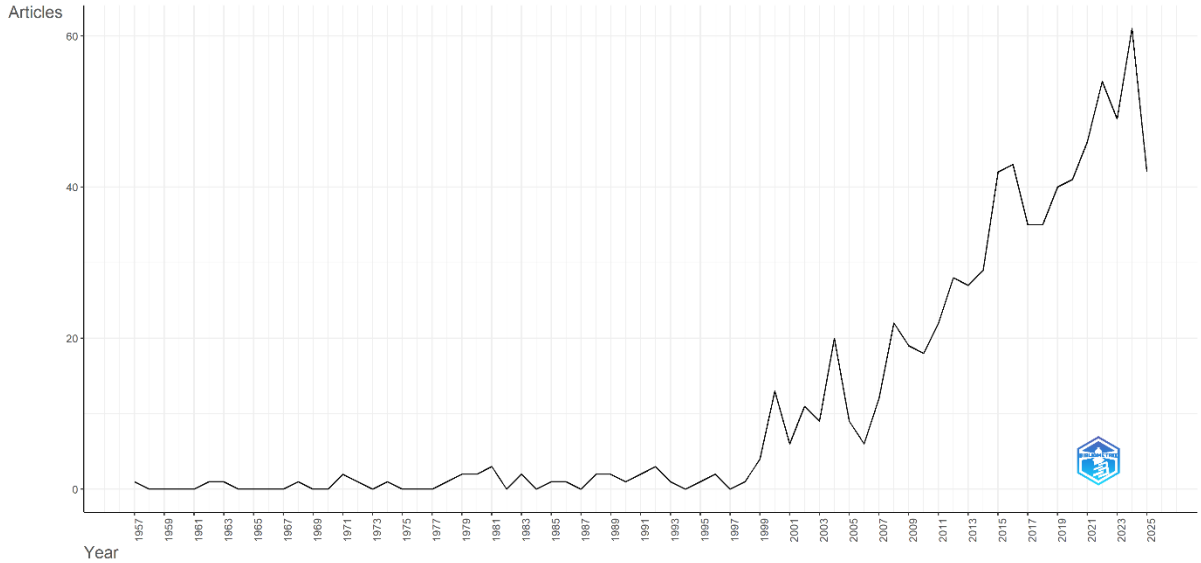

Fig 1: Annual Scientific Production

From 1957 to 1995, the publication volume in the field remained very low and relatively flat, with fewer than five articles published annually, indicating that the research was either nascent, scattered, or received limited academic attention. A modest rise began in the late 1990s (1996–2005), reflecting early signs of scholarly interest, though the growth was inconsistent with noticeable fluctuations. The period from 2006

to 2021 marks a phase of rapid expansion, particularly after 2010, with annual output surpassing 20 articles by 2014 and peaking above 60 in both 2021 and 2023—highlighting a surge in visibility and productivity. However, a noticeable dip in 2024–2025 is likely due to incomplete indexing or data delays, a common occurrence in bibliometric datasets for the most recent years, and does not necessarily indicate a true decline in research activity.

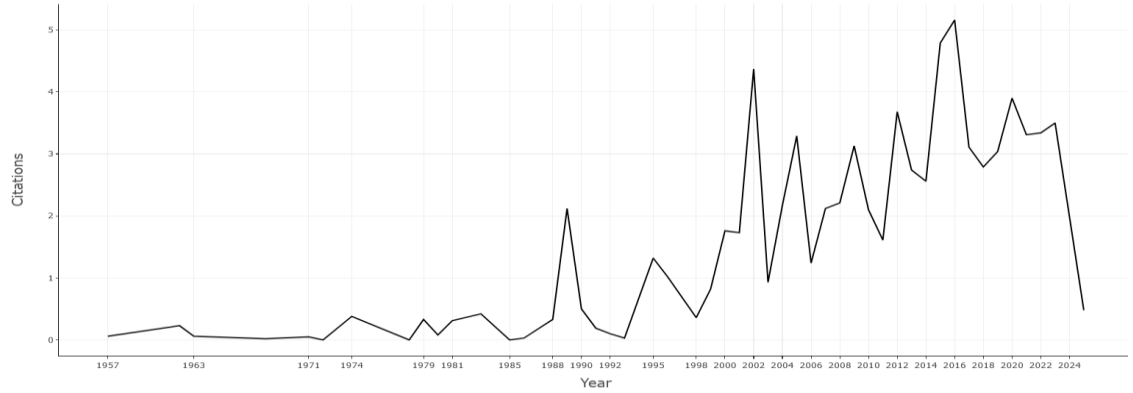

Fig 2 : Average Citations per year

From 1957 to 1997, the average number of citations per year remained very low or near zero, indicating minimal citation impact likely due to a small volume of publications, limited academic interest, and challenges in accessing or indexing older works. A noticeable rise in citations began in the late 1990s, with intermittent peaks between 2001 and 2016—particularly in 2002, 2007, 2014, and 2016—suggesting the emergence of highly cited publications and growing scholarly attention. Between 2017 and 2023, the citation rate remained relatively strong but showed variability, which is typical in bibliometric trends due to factors such as document type (e.g., review articles often receiving more citations), shifting topic relevance, and delays in publication and citation accumulation. The sharp decline observed in 2024 and 2025 is not indicative of reduced impact but is instead attributed to the short time frame available for new publications to garner citations, a common limitation in recent bibliometric data.

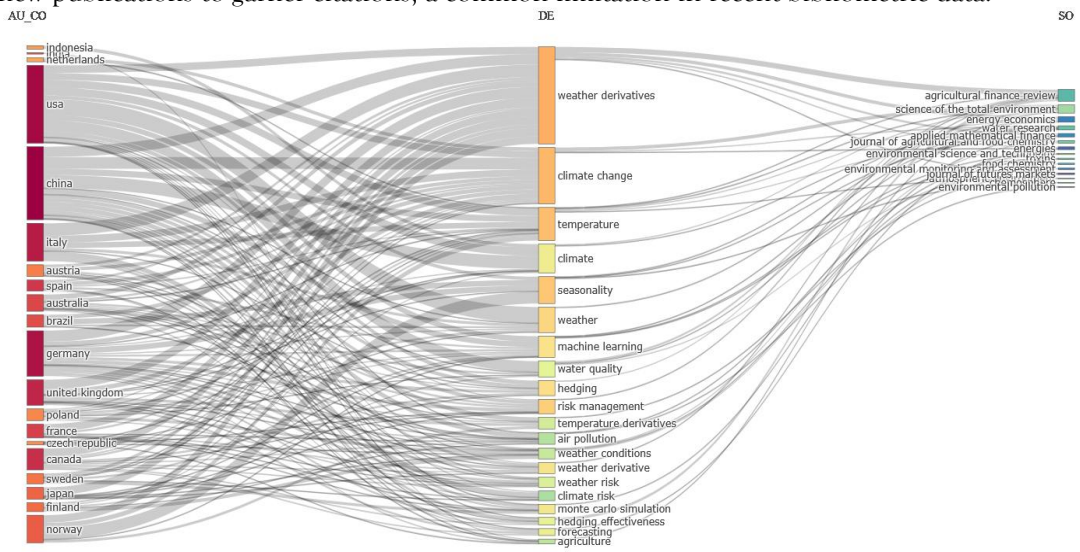

Fig 3: Three Field Plot

The three-field plot provides a visual representation of the relationships between author countries (AU_CO), author-assigned keywords (DE), and source journals (SO) in the research dataset. The left column highlights the geographic distribution of research contributions, with countries such as the USA, Germany, the UK, Canada, Australia, and Indonesia showing significant involvement—particularly in topics like “weather derivatives” and “climate change.” These strong connections suggest both thematic focus and active international collaboration. The central keywords reveal the core research themes, with “weather derivatives” as the most frequently used term, alongside other climate-related concepts such as “temperature,” “climate,” and “seasonality.” On the right, theprimary journals publishing in these areas

include Agricultural Finance Review and Science of the Total Environment, indicating the interdisciplinary nature of the research, spanning environmental science, economics, and finance.
The thickness of the connecting lines illustrates the strength of association between countries, keywords, and journals—where thicker lines signify more frequent co-occurrence. This structure allows for the identification of research trends and patterns, offering opportunities to explore questions such as how thematic priorities vary by country or which journals lead in publishing on specific topics. However, critical considerations must be taken into account: the dataset relies solely on Scopus, which may limit coverage; author keywords can be subjective; and the absence of time-based segmentation may obscure temporal trends. Additionally, normalization of publication counts could provide a clearer view of relative research contributions. For a more comprehensive analysis, integrating indexed keywords and temporal data would enhance the depth and reliability of interpretation.

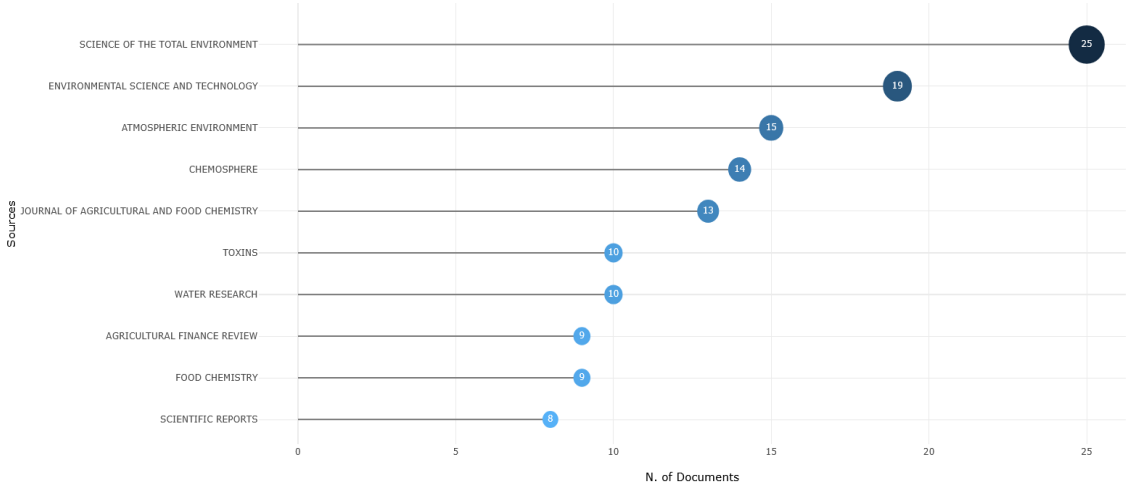

Fig 4: Most Relevent Sources

Fig 4 graph displays the most relevant sources based on the number of documents published in the dataset. Science of the Total Environment leads significantly with 25 documents, followed by Environmental Science and Technology with 19, and Atmospheric Environment with 15, indicating that environmental journals dominate the dissemination of research in this field. Other prominent sources include Chemosphere, Journal of Agricultural and Food Chemistry, and Water Research, each contributing over 10 articles. The presence of journals like Agricultural Finance Review and Food Chemistry reflects the interdisciplinary nature of the field, bridging environmental science, agriculture, and food systems. The variation in source types suggests a broad thematic scope and a diverse academic audience engaging with this research area.

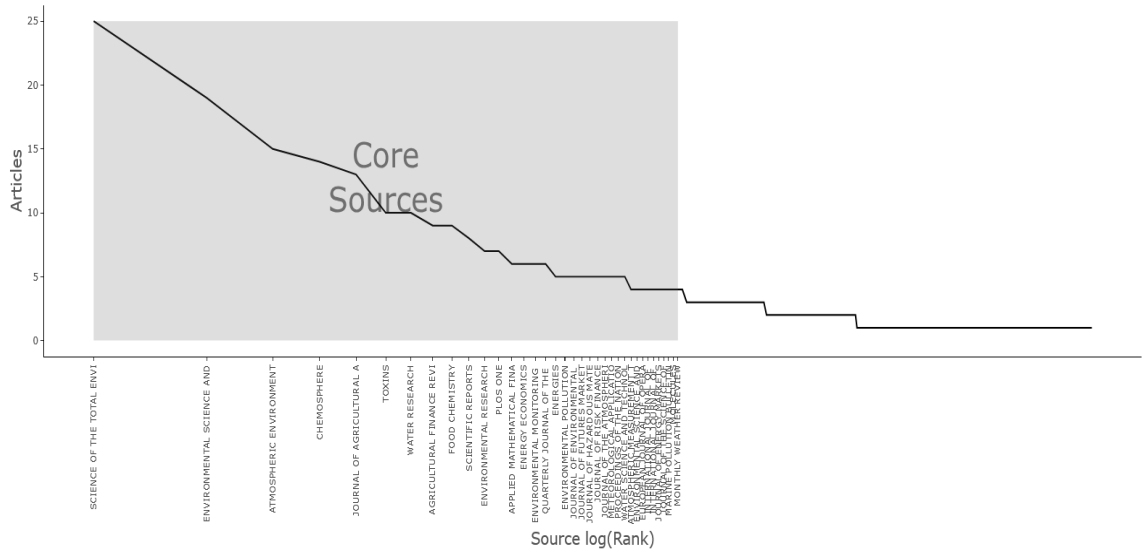

Fig 5: Core Sources by Bradford's Law

From Fig 5, the graph represents the distribution of core sources based on Bradford's Law, which helps identify the most productive journals in a given research field. The shaded area labeled "Core Sources"

indicates a small group of journals that contribute a disproportionately large number of articles—typically the most influential or central to the field. In this case, journals like Science of the Total Environment, Environmental Science and Technology, and Atmospheric Environment fall within this core zone, collectively accounting for the highest publication output. As we move to the right along the x-axis (log of source rank), the number of articles per journal decreases sharply, illustrating the law's principle that a few journals produce the majority of content, while many others contribute only a small number of papers. This pattern confirms the presence of a concentrated core of key sources, which are essential for researchers to follow in order to stay updated with major developments in the field.

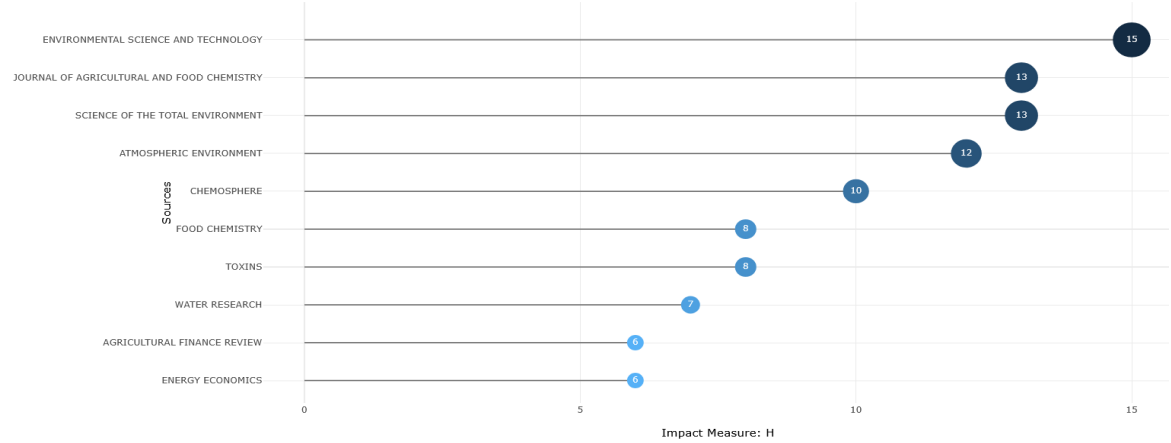

Fig 6: Source's Local Impact

From Fig 6 , the graph illustrates the local impact of sources based on the H-index, which reflects both the productivity and citation impact of publications within the dataset. Environmental Science and Technology leads with the highest H-index (15), indicating it hosts the most influential and frequently cited research in this field. Close behind are the Journal of Agricultural and Food Chemistry and Science of the Total Environment, each with an H-index of 13, highlighting their strong scholarly contribution. Journals like Atmospheric Environment and Chemosphere also show substantial impact, while others such as Agricultural Finance Review and Energy Economics exhibit lower H-index values, suggesting more modest influence locally. Overall, this visualization identifies the journals that are not only prolific but also central to shaping the academic discourse in this research area.

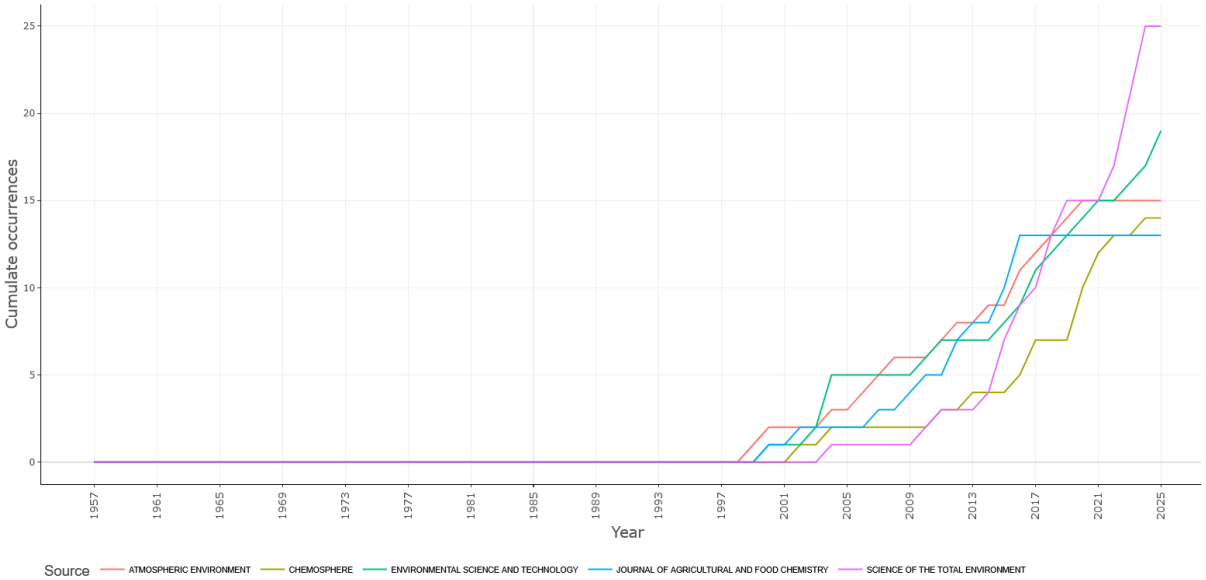

Fig 7: Source's Production Over Time

The data in Fig 7 reveals the cumulative production of key sources over time, highlighting trends in research output across top journals. All sources began contributing to the field after 2000, with Science of the Total Environment exhibiting the most rapid growth, especially after 2020, reaching the highest number of cumulative publications. Environmental Science and Technology and the Journal of Agricultural and Food Chemistry also show steady and significant increases in output, suggesting

sustained relevance. Atmospheric Environment and Chemosphere display more moderate but consistent publication activity. Overall, the chart indicates an accelerating publication trend in these journals over the past two decades, reflecting growing academic interest and expansion in this research domain.

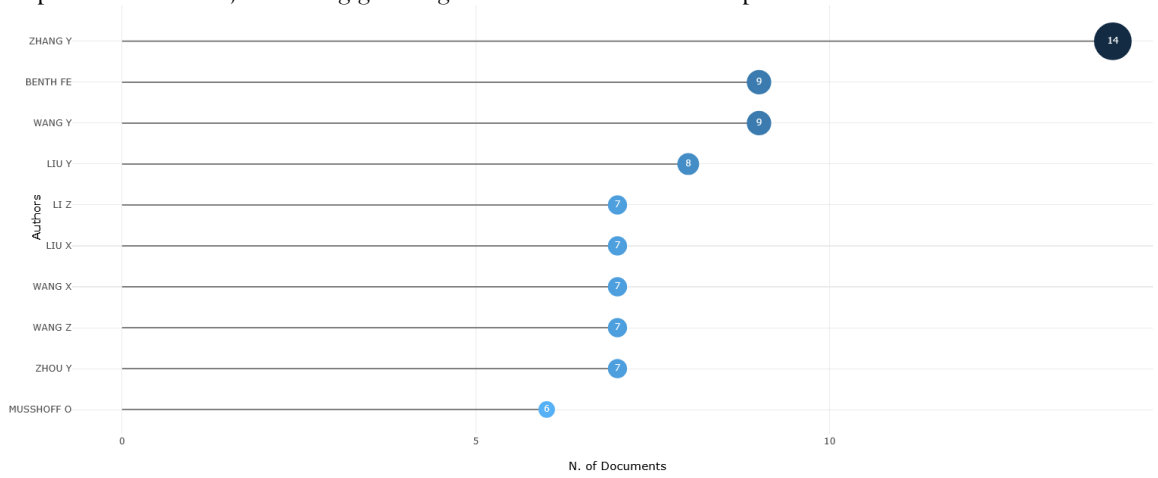

Fig 8: Most Relevent Authors

Theis graph displays the most relevant authors in the dataset based on the number of publications. Zhang Y stands out as the leading contributor with 14 documents, significantly ahead of the others. Benth FE and Wang Y follow with 9 documents each, indicating their strong engagement in the field. Authors like Liu Y, Li Z, and several others including Wang X, Wang Z, and Zhou Y have contributed consistently with 7–8 publications each. This distribution suggests a core group of prolific researchers driving the literature, with Zhang Y emerging as a central figure in advancing the research topic.

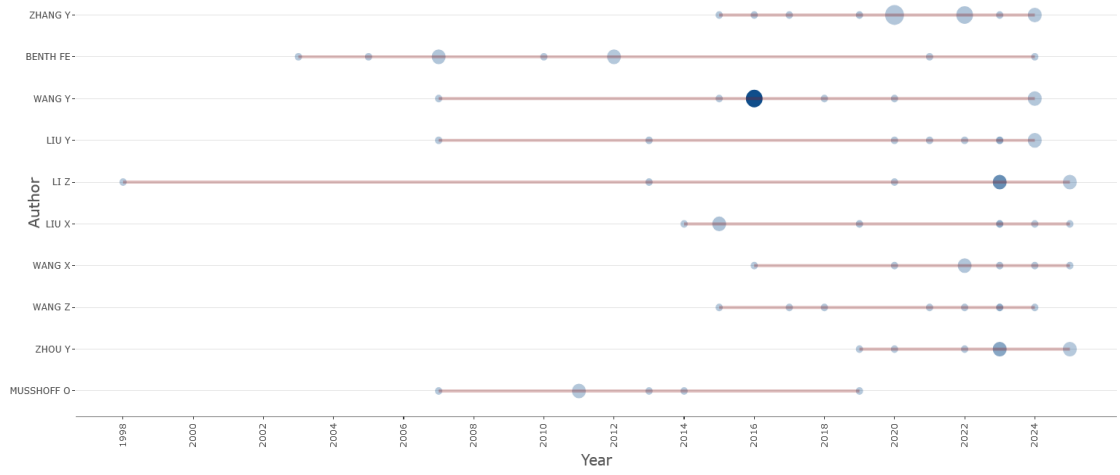

Fig 9: Author's Production Over Time

The above analysis of author publishing careers reveals distinct patterns of productivity and influence across time. Zhang Y emerges as a prolific and steadily growing contributor, especially in recent years. Authors like Wang Y and Benth FE have demonstrated significant impact within specific periods—Wang Y notably around 2016 with highly cited work on atmospheric chemistry, while Benth FE had a concentrated impact in the mid-2000s in the field of weather derivatives. Musshoff O also falls into this category, with a longer but less frequent publication history focused on agricultural risk. In contrast, Liu Y, Li Z, Liu X, and Zhou Y experienced a sharp citation peak due to a shared recent publication on foldable silicon solar cells, indicating both collaboration and a breakthrough topic.

Several authors (Wang X, Wang Z, Liu Y) show increasing productivity and citation impact in recent years, suggesting emerging influence and possibly expanding research programs. The shared authorship on a highly cited 2023 Nature article also highlights strong collaboration among a subset of authors. Furthermore, while some researchers focus deeply on specific themes (e.g., weather derivatives or air pollution), others like Wang X exhibit interdisciplinary output across environmental health and food safety. Overall, the data suggests a maturing research field with new contributors gaining prominence alongside established authors whose past work continues to shape the discourse.

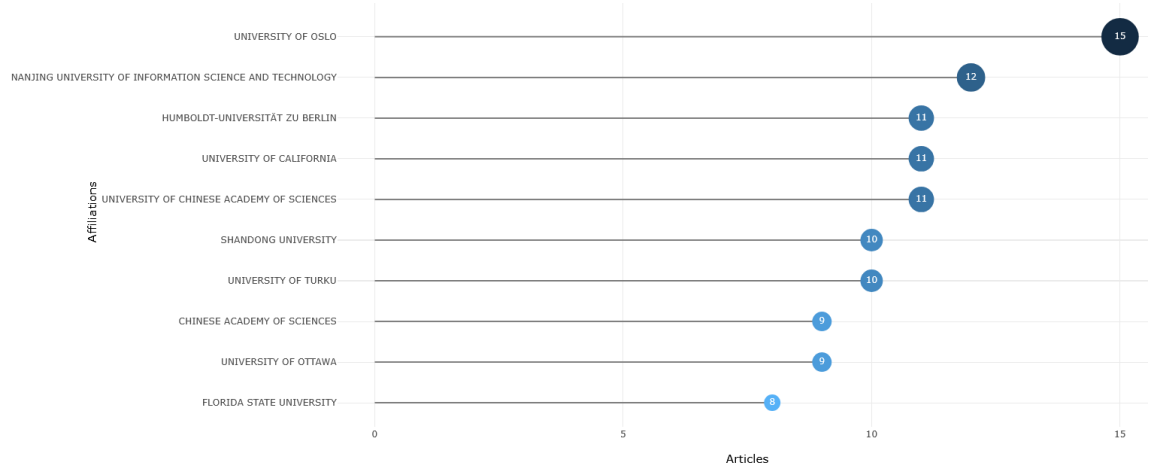

Fig 10: Most Relevent Affiliations

From the Fig 10, illustrates the most relevant institutional affiliations based on the number of published articles. The University of Oslo leads with the highest output of 15 articles, indicating a significant contribution to the research area. It is followed by the Nanjing University of Information Science and Technology with 12 articles, and Humboldt-Universität zu Berlin, University of California, and the University of Chinese Academy of Sciences, each contributing 11 articles. Other notable institutions include Shandong University and the University of Turku (10 articles each), and the Chinese Academy of Sciences, University of Ottawa, and Florida State University, which also appear as influential affiliations. This distribution highlights a strong presence of both European and Chinese institutions, suggesting international collaboration and diverse geographic interest in the field.

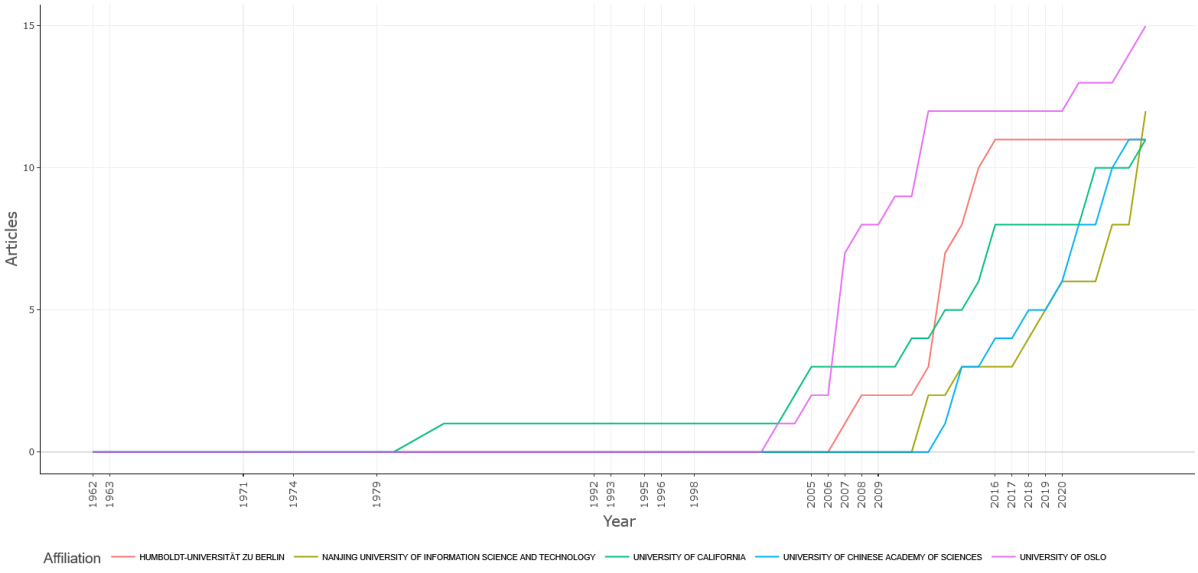

Fig 11: Affiliation Production Over Time

The Fig 11 illustrates the research output over time from six key affiliations. The University of California began contributing as early as the 1980s but showed gradual growth until 2005, after which its output steadily increased. The University of Oslo, though a later entrant, has shown rapid and consistent growth since around 2012, now leading with the highest cumulative number of articles. The University of Chinese Academy of Sciences and Nanjing University of Information Science and Technology both began publishing more significantly after 2010 and have demonstrated steady increases. Meanwhile, Humboldt-Universität zu Berlin saw a noticeable rise starting around 2009, maintaining a competitive pace. Overall, the data shows that while some institutions have long publishing histories, others have emerged more recently but with strong momentum, reflecting shifting research activity and expanding international involvement in the field.

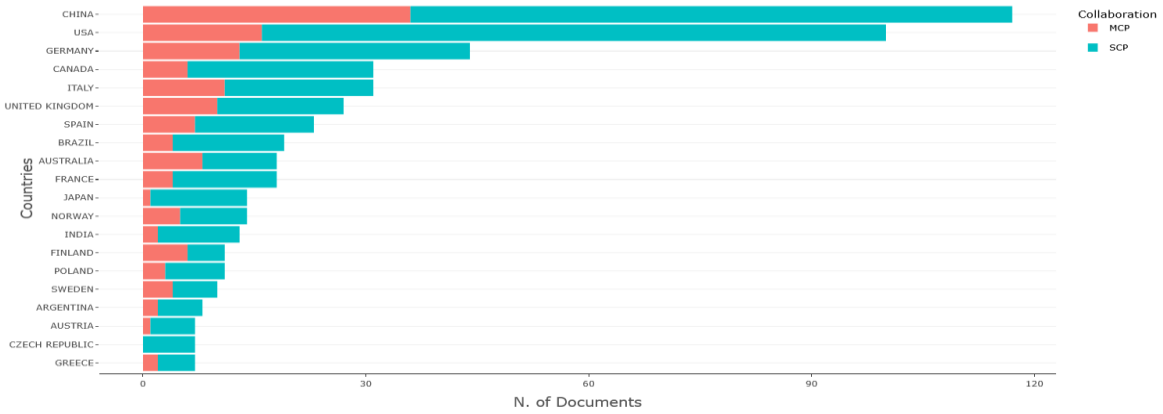

Fig 12: Corresponding Author's Countries

The Fig 12 displaying Corresponding Author's Countries highlights the global distribution of research contributions, with China clearly leading, indicated by the highest number of corresponding authorship articles. This dominance reflects China's growing emphasis and investment in research and academic output. Following China, the United States and several European countries such as Germany, Norway, and the United Kingdom also show notable contributions, though at a comparatively lower scale. This distribution demonstrates a strong presence of both developed and emerging research economies, suggesting increased international engagement and collaboration in scientific research.

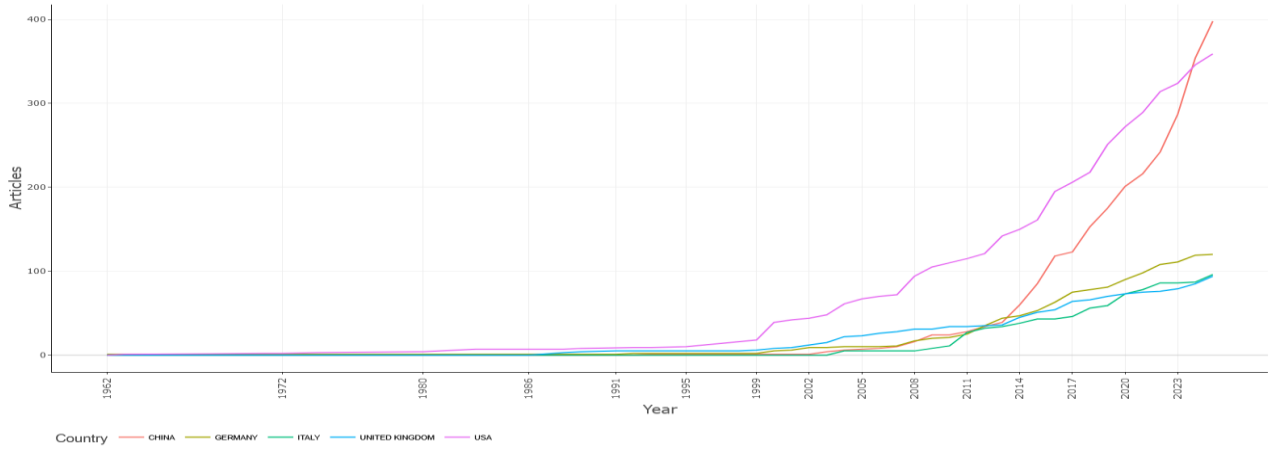

Fig 13: Countries Production over Time

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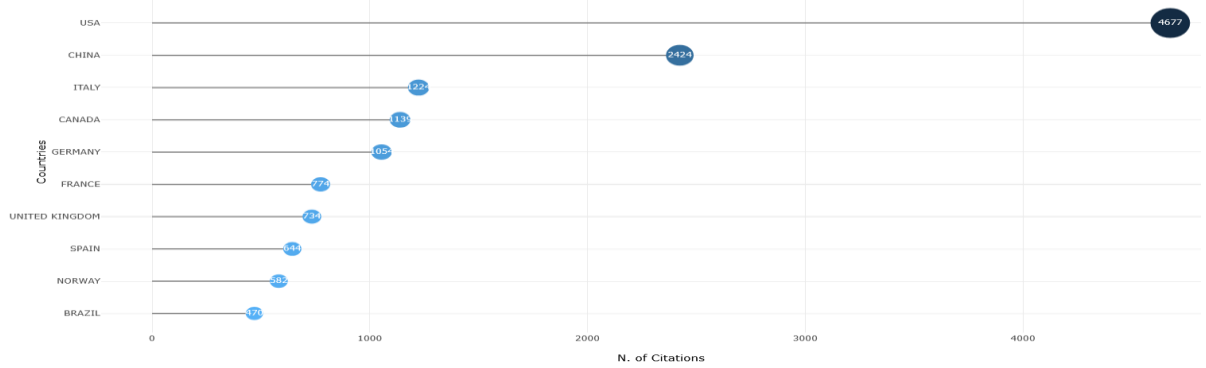

Fig 14: Most Cited Countries

This Fig 14 shows the number of citations received by the top ten most cited countries. The USA leads significantly with 4,677 citations, followed by China with 2,424—both far ahead of the rest. Italy, Canada, and Germany form the next tier with 1,122, 1,131, and 1,035 citations respectively, indicating moderate research influence. France, the United Kingdom, Spain, Norway, and Brazil trail with fewer than 800 citations each, suggesting comparatively lower international research impact. Overall, the USA and China dominate in citation counts, highlighting their global research influence and recognition.

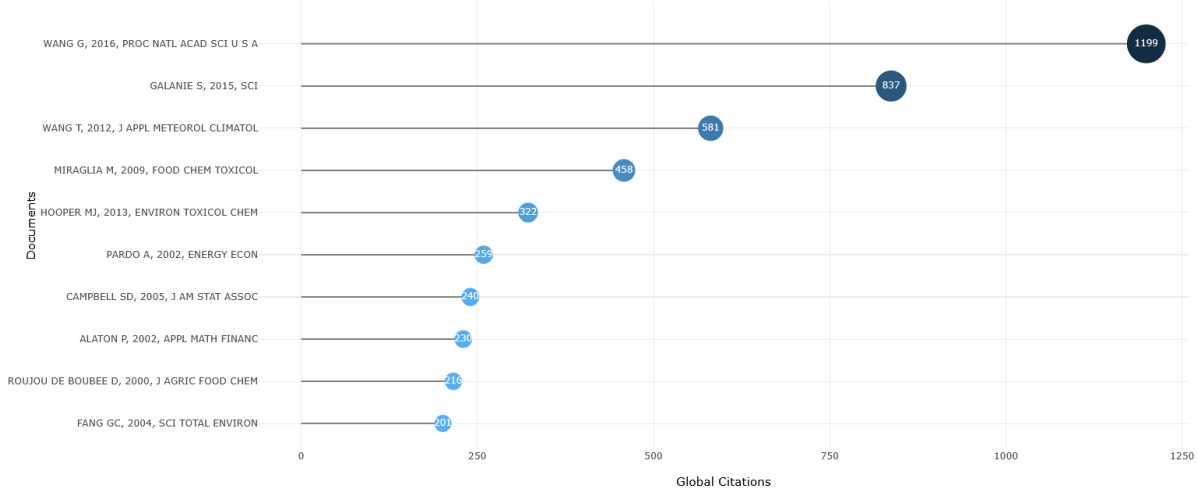

Fig 15: Most Global Cited Documents

The Fig 15 displays the top ten most globally cited documents, highlighting their significant impact in scholarly research. The document by Wang G (2016) published in PNAS stands out as the most influential, with 1,199 citations. It is followed by Galanie S (2015) with 837 citations and Wang T (2012) with 581 citations, indicating high relevance in their respective fields. Other notable works include those by Miraglia M (2009) and Hooper MJ (2013), with 458 and 322 citations respectively. The remaining documents each have citation counts ranging from 301 to 258, showing substantial but comparatively lesser influence. Overall, the graph emphasizes a small number of highly cited papers that have made a major impact in global research.

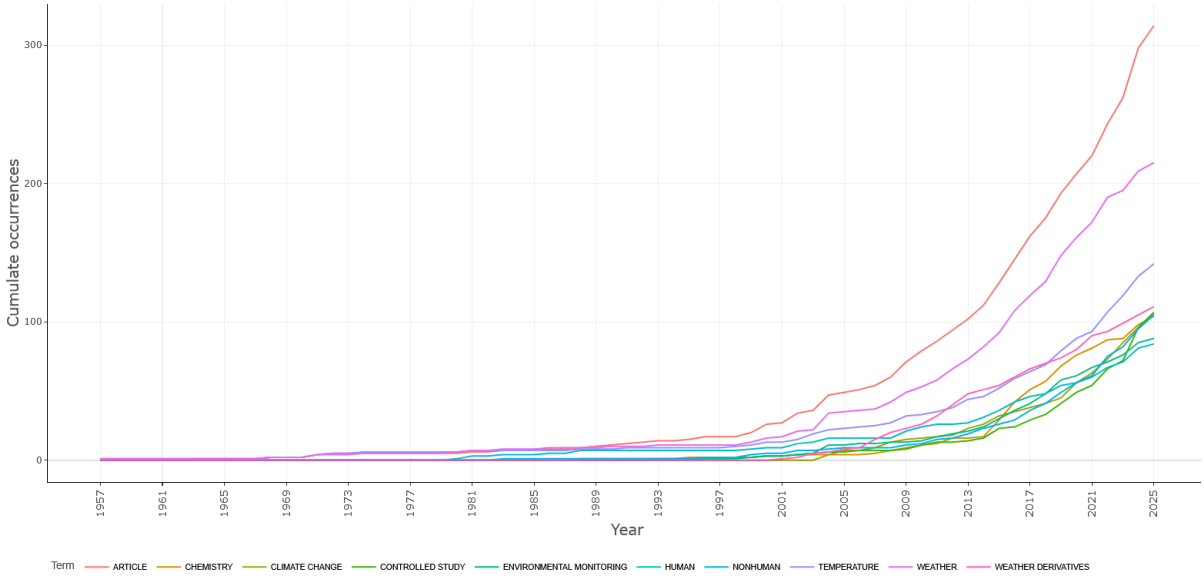

Fig 16: Word's Frequency Over Time:

The Fig 16 presents the cumulative frequency of selected terms over time from 1957 to 2025, reflecting trends in academic and research focus. The term "ARTICLE" shows the highest and most consistent growth, particularly accelerating after 2005, indicating a sharp rise in academic publications. "WEATHER DERIVATIVES" and "TEMPERATURE" also show significant increases, suggesting growing interest in climate and financial risk topics. Other terms like "CLIMATE CHANGE", "ENVIRONMENTAL MONITORING", and "WEATHER" display steady upward trends, especially post-2000, aligning with global environmental concerns. Less frequent but rising terms such as "CONTROLLED STUDY",

"HUMAN", and "NONHUMAN" suggest expanding research scopes. Overall, the graph highlights the increasing emphasis on environmental, scientific, and climate-related research over the decades.

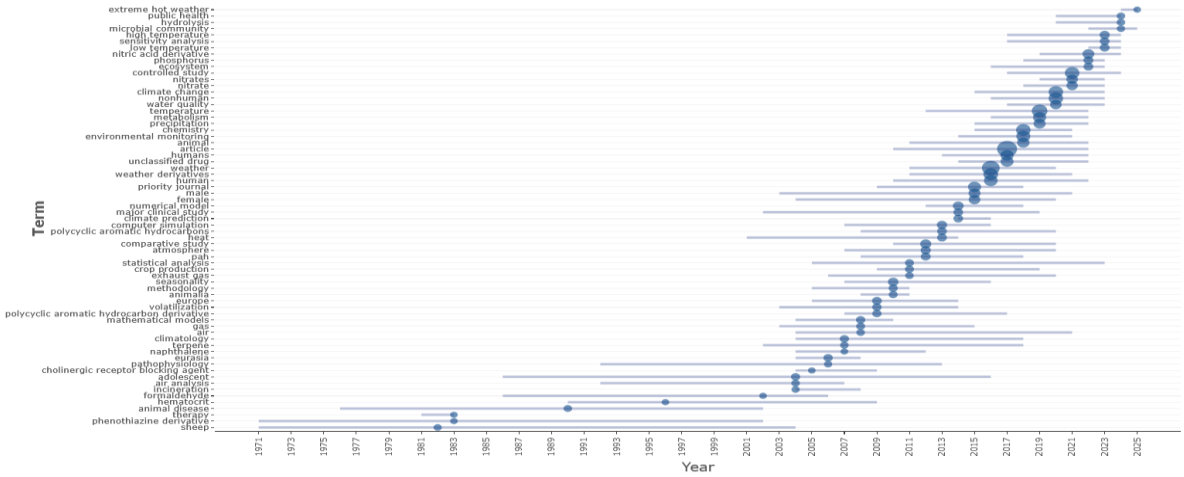

Fig 17: Trend Topics

The Fig 17 depicts the evolution of trend topics over time from 1971 to 2025, highlighting when specific terms gained research attention and how long they remained active. Earlier years (1970s–1990s) show sparse activity, with only a few isolated topics such as "sheep," "phenothiazine derivative," and "animal behavior." However, from the early 2000s onward, there is a marked increase in both the number and diversity of trending research topics. Notable terms like "climate change," "weather derivatives," "temperature," and "environmental monitoring" appear consistently and grow in frequency, especially post-2010, indicating sustained and rising interest. The density of points and bars from 2010 onward shows rapid expansion in topic diversity and popularity, reflecting the dynamic and interdisciplinary nature of modern research, particularly around climate, health, and environmental issues.

The trend topics plot reveals a significant rise in research activity and keyword diversity from around the year 2000 onward, indicating a surge in global scientific interest and publication output. Topics related to climate and the environment, such as climate change, temperature, environmental monitoring, and extreme hot weather, have gained notable traction, suggesting growing awareness and urgency around environmental and climate-related issues. At the same time, chemical and compound-related keywords like nitrates, PAHs, and formaldehyde reflect continued research into pollutants and industrial effects on ecosystems. The presence of terms like statistical analysis, mathematical models, and controlled study shows the increasing importance of robust methodologies in analyzing complex scientific problems. Terms related to human and animal studies suggest a broadening scope that includes both biomedical and environmental health.

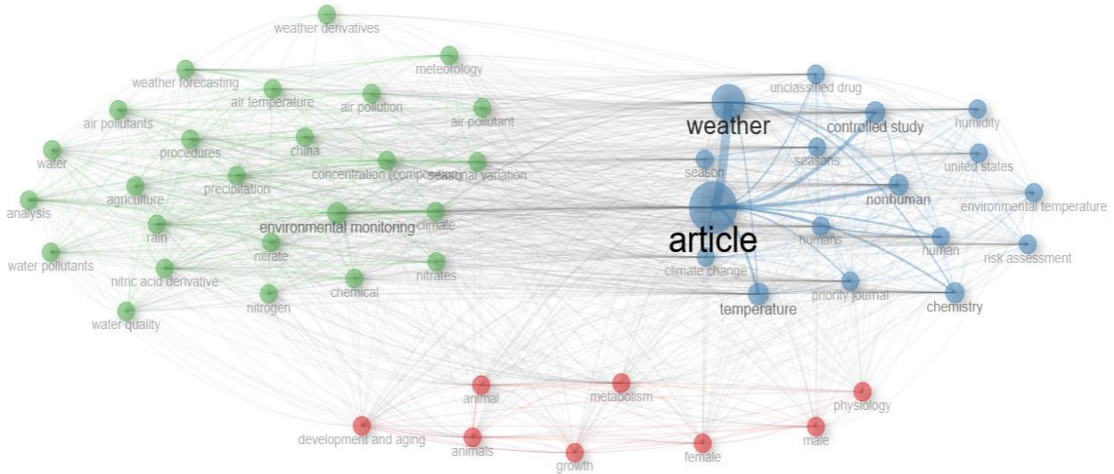

Fig 18: Co-occurrence Network

The co-occurrence network effectively maps the conceptual structure of the research corpus, revealing three distinct keyword communities identified using the walktrap algorithm. The green cluster centers on environmental pollution and monitoring, highlighting themes like air pollution, nitrates, water quality, and agriculture, with geographic relevance suggested by terms like China. The blue cluster is more broadly focused on environmental and climatic themes, including weather, climate change, temperature, and controlled study, and blends environmental science with elements of health and policy research. Meanwhile, the red cluster deals with biological and physiological research, evidenced by terms like animal, metabolism, development and aging, and physiology. The term article appears as the most central and interconnected keyword, likely reflecting its frequent appearance in publication metadata and its bridging role across different subfields.

This structure indicates an interdisciplinary research landscape, where environmental science overlaps with health, biology, and policy. The strong centrality of terms like weather, temperature, and environmental monitoring points to a growing emphasis on environmental risk assessment and the impact of climate variables. The presence of specialized yet interlinked clusters suggests opportunities for more cross-disciplinary research, particularly between environmental and biological sciences. Future work could include a temporal evolution of this network to reveal emerging trends or topic declines, and deeper author or geographic overlays could identify leading contributors or regional strengths. Overall, this co-occurrence network offers a powerful lens through which to understand the complexity, depth, and direction of current research in the domain.

The co-occurrence network graph visualizes the relationships between frequently used keywords in the dataset, grouped into thematic clusters. Three main clusters are evident: blue, focusing on climate and environmental variables (e.g., weather, temperature, climate change, humidity, controlled study); green, centered on pollution, environmental monitoring, and agricultural terms (e.g., environmental monitoring, nitrate, air pollution, precipitation, water pollutants); and red, highlighting biological and physiological research (e.g., animal, metabolism, male, female, development and aging). The terms article and weather occupy central positions, indicating they are highly interconnected with multiple other topics. This suggests that publications frequently address environmental and climatic themes alongside health or methodological components. The dense network of links between clusters reflects interdisciplinary research, connecting environmental science, public health, and biological systems.

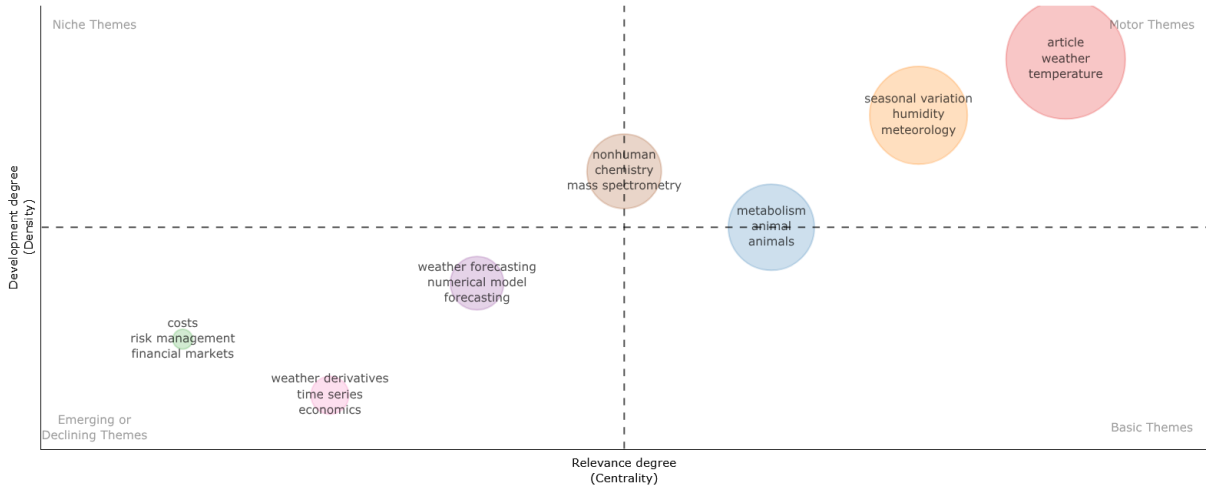

Fig 19: Thematic Map

The strategic map provides a comprehensive visualization of the intellectual structure of the research field based on keyword co-occurrence analysis from SCOPUS data. Themes are categorized by their centrality (importance within the field) and density (degree of development). The most influential and mature area is the motor theme cluster around "article weather temperature," indicating a well-established research focus on environmental impacts such as marine and water pollution in relation to weather and temperature. In contrast, niche themes such as "nonhuman chemistry mass spectrometry" and "metabolism in animals" reflect highly developed but specialized areas with limited broader influence. Emerging or declining themes, such as "costs and financial markets," "weather derivatives," and "forecasting models," appear underexplored or losing traction, while seasonal variation lies near the motor quadrant, suggesting it is also a critical and evolving topic.

To deepen this analysis, a review of the most central articles and their publishing journals is essential for understanding specific trends and methodological approaches. However, several limitations must be acknowledged: keyword selection methods, SCOPUS database coverage, and clustering parameters (e.g., no stemming, no repulsion) could affect the granularity and interpretability of the results. Additionally, since co-occurrence does not imply causation, combining this approach with citation or semantic analysis, along with temporal and sensitivity assessments, would provide a richer, more nuanced understanding of the research landscape and its trajectory.

The thematic map categorizes research themes based on their development (density) and relevance (centrality) within the field. In the top-right quadrant (Motor Themes), keywords like article, weather, and temperature are both well-developed and highly relevant, representing core, driving topics in the research landscape. The bottom-right quadrant (Basic Themes) contains metabolism, animal, and animals, which are central to the field but less developed, suggesting foundational topics with room for further exploration. In the top-left quadrant (Niche Themes), nonhuman, chemistry, and mass spectrometry appear well-developed but are more isolated from the core of the field, indicating specialized or highly technical research areas. The bottom-left quadrant (Emerging or Declining Themes) includes terms like weather derivatives, time series, economics, and risk management, suggesting underdeveloped areas that may either be gaining traction or losing relevance. Overall, the map highlights a research field anchored by environmental and climate themes, with emerging interest in interdisciplinary links to finance, forecasting, and biology.

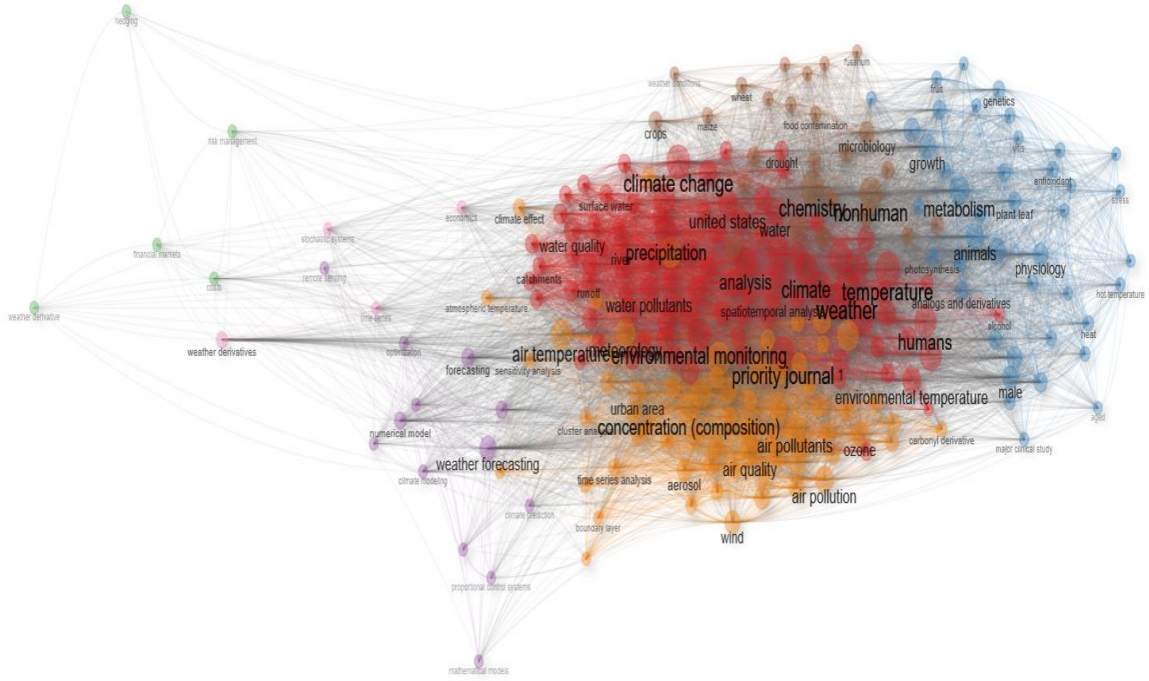

Fig 20: Co-Word Network Analysis

This co-word network graph illustrates the interconnected structure of research themes, revealing a dense core and multiple thematic clusters. The central cluster (red) is dominated by core environmental and climate-related terms such as climate change, precipitation, water pollutants, environmental monitoring, and air temperature, reflecting the centrality and multidisciplinary relevance of climate and pollution studies. The blue cluster on the right is biologically focused, encompassing terms like metabolism, animals, physiology, and growth, suggesting research linking environmental factors to biological impacts. The orange and purple clusters represent technical and modeling themes such as air pollution, forecasting, and numerical models, indicating the methodological backbone of environmental analysis. On the periphery, the green and pink clusters focus on finance-related topics like weather derivatives, risk management, and financial markets, highlighting niche but emerging intersections between climate science and economics. Overall, the network reveals a highly interdisciplinary research ecosystem centered on climate and environmental science, bridging into biology, public health, modeling, and finance.

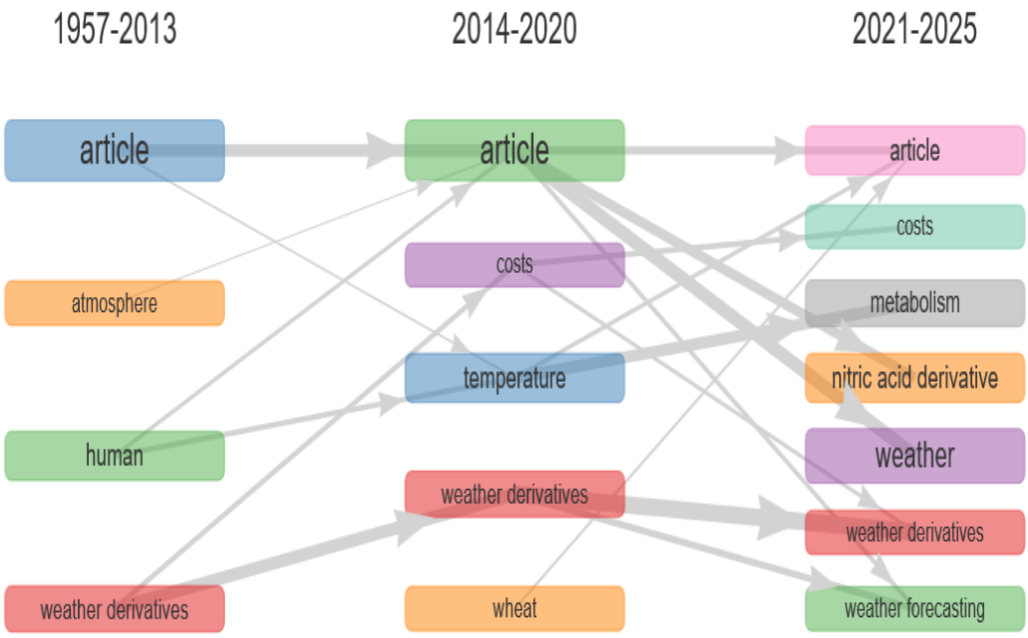

Fig 21: Thematic Evolution

The bibliometric analysis, based on SCOPUS data using merged unigrams and the walktrap clustering algorithm, reveals a clear thematic evolution in climate and weather-related research from 1957 to 2025. Initially, foundational terms like "article," "human," and "atmosphere" dominated, but over time, the field has shifted toward more specialized and application-oriented topics. “Weather derivatives” emerged as a niche topic in early periods, gradually gaining prominence and maintaining relevance in the latest period (2021–2025), indicating its growing practical importance in areas such as financial risk management. The emergence of new terms like "costs," "metabolism," "nitric acid derivative," and "weather forecasting" in recent years reflects expanding interdisciplinary interests and a move toward economic, environmental, and biological integration. Simultaneously, older topics like “atmosphere” and “human” have faded from central focus, likely being absorbed into broader or more technical themes.

Strategic maps across the three timeframes support this thematic shift. In 1957–2013, “article,” “weather,” and “temperature” were motor themes, while “weather derivatives” and “weather forecasting” were still emerging. By 2014–2020, “climate change” became a basic theme, and “weather derivatives” began moving toward the center. In 2021–2025, the map reveals a diversification of central themes, including “human,” “nitrates,” and “meteorology,” with niche areas like “predictive control systems” and “costs” indicating increasing specialization. The overall trend shows growing complexity and practical orientation in the field, especially around risk management and predictive systems. To deepen insights, future studies should use phrase-based (n-gram) keyword analysis, conduct deeper content and network analysis, and validate results through cross-database comparisons.

The thematic evolution diagram illustrates the progression and transformation of research themes over three time periods—1957–2013, 2014–2020, and 2021–2025. The continuity of the theme “article” across all three phases suggests a foundational and persistent focus in the literature. Themes such as “weather derivatives” and “costs” emerge around 2014–2020 and continue into 2021–2025, reflecting growing interest in climate-related financial risk and economic implications. “Temperature” in the middle period appears to have branched into more specialized contemporary topics like “weather,” “weather forecasting,” and “nitric acid derivative,” indicating a shift toward more applied and technical environmental research. The recent emergence of “metabolism” and the return of “human” and “weather derivatives” in new contexts highlight an interdisciplinary expansion, likely integrating biological and climate sciences. This evolution reflects both thematic deepening and diversification in response to advancing research methodologies and pressing environmental challenges.

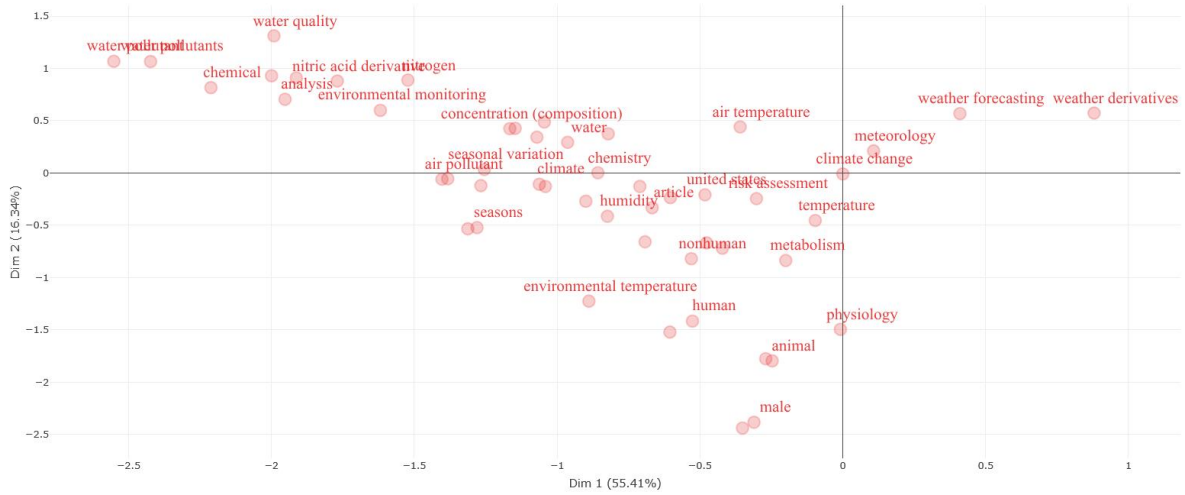

Fig 22: Factorial Analysis

The factorial analysis using Multiple Correspondence Analysis (MCA) provides a structured overview of the research landscape from SCOPUS, revealing two key dimensions. Dim 1 (explaining 55.41% of the variance) distinguishes environmental pollution research (e.g., "water quality," "chemical analysis") from physiological studies (e.g., "nonhuman metabolism," "human physiology"), suggesting a spectrum from environmental impact to biological responses. Dim 2 (16.34% variance) separates atmospheric/environmental chemistry at the top (e.g., "water pollutants," "air quality") from human/animal physiological responses to environmental changes at the bottom. The clusters identified align with specific themes: Cluster 1 focuses on water quality and pollution, Cluster 2 on climate and risk assessment, Cluster 3 on physiological responses to environmental temperature, and Cluster 4 on weather forecasting and climate change.

This analysis underscores the interdisciplinary nature of the field, combining environmental science, atmospheric chemistry, and biological research. The positioning of keywords highlights dominant areas like water monitoring and weather modeling, while gaps in the map indicate potential under-explored areas. For future research, refining keyword selection, testing stemming, and experimenting with dimensional and clustering parameters could enhance clarity. Qualitative analysis of key documents in each cluster and cross-database comparisons are recommended to validate findings and uncover database-specific biases. Overall, the map offers a powerful foundation for generating data-driven hypotheses and identifying evolving research trends.

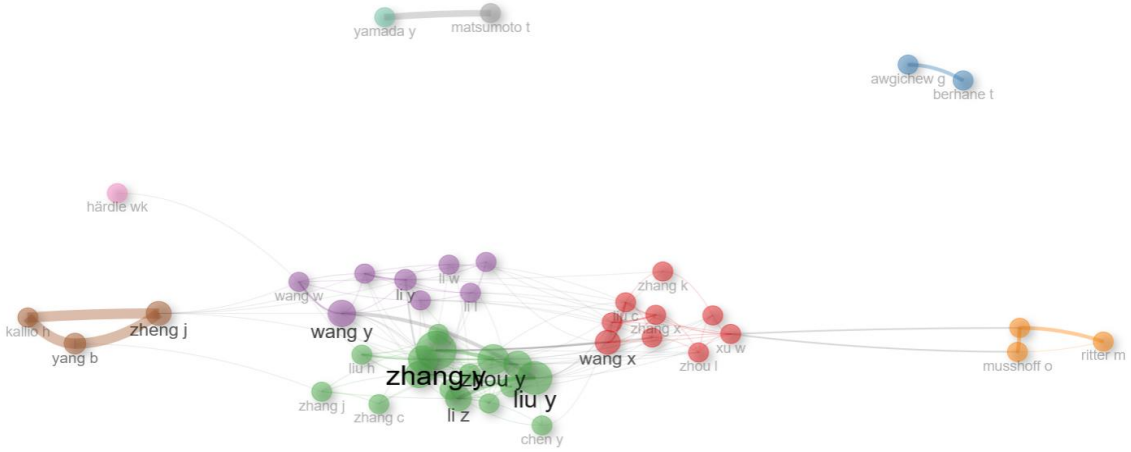

Fig 23: Collaboration Network

The author collaboration network reveals a fragmented structure with multiple distinct communities, indicating that research collaborations are concentrated within specific groups rather than across the field. Using the Walktrap algorithm and association strength normalization, several key communities were identified—such as the green cluster led by 'zhang Youy' and 'Liu y', and the purple and red clusters featuring 'Wang w', 'zhang k', and others—each likely representing different disciplinary subfields. Node size highlights influential authors, with 'zhang Youy', 'Wang w', and 'kallio h' appearing as central figures.

The lack of interconnectivity suggests potential collaboration barriers—geographic, institutional, or thematic—while isolated clusters hint at limited integration. This network offers opportunities for fostering cross-community collaboration and understanding how prominent researchers shape their domains. However, results are bounded by the dataset's scope and timeframe, and further analysis using alternative centrality measures or time-based network evolution could deepen insights into the structure and dynamics of research collaboration.

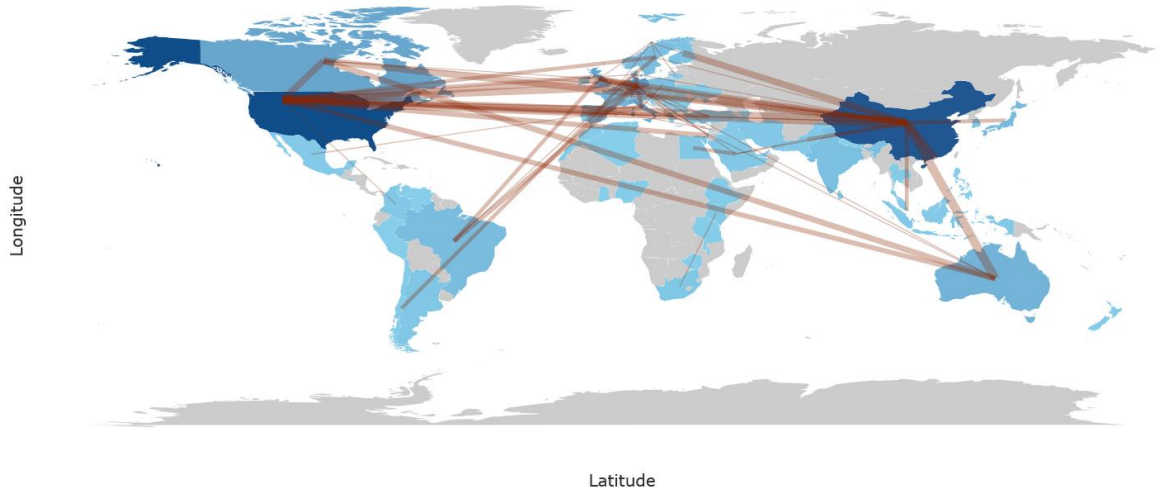

Fig 24: Countries Collaboration World Map

The "Countries' Collaboration World Map" reveals key global research hubs, with the United States and China emerging as the most prominent contributors, followed closely by major European nations like the UK, Germany, France, and Italy. Strong international collaboration is evident, especially through transatlantic ties between the US and Europe, US-China partnerships, and intra-European and Australia-Asia connections. The map highlights the dominance of North America and Europe, along with the rise of Asia, particularly China, as a global research leader. However, since the data is based on SCOPUS, inherent biases favoring English-language and Western publications must be considered. While the map shows the existence of collaborations, it doesn't reflect their depth or impact, and some partnerships may go unrepresented due to limitations in data capture (e.g., patents or informal collaborations). For deeper insights, researchers should consider analyzing collaboration trends over time, focusing on specific regions or topics, using network analysis to identify central actors, and integrating qualitative approaches. These insights can guide policy decisions on funding and international cooperation, making the map a valuable tool for strategic research planning.

5. CONCLUSION

This bibliometric study provides a comprehensive overview of the global research landscape on weather derivatives, highlighting the evolution of themes related to climate risk, temperature-based pricing, and financial modeling from 1957 to 2025. By analyzing 778 documents from 457 sources using the Bibliometrix package in R Studio, the study uncovers a steady annual growth rate of 5.65% in publications, an average of 27.75 citations per document, and moderate international collaboration (26.99%). The results underscore the field's interdisciplinary and fragmented nature, with contributions from finance, climatology, insurance, and risk management, yet lacking cohesive integration and updated methodological frameworks. The intellectual foundation of the field appears grounded in early theoretical pricing models, but more recent literature emphasizes emerging risks linked to climate variability and the need for dynamic pricing tools.

Despite the growing academic attention and collaborative efforts, the findings reveal considerable gaps in policy integration, cross-disciplinary research, and practical application of weather derivatives in emerging markets. The analysis of keywords and author networks suggests diverse thematic interests but calls for greater coherence in conceptual development. Moving forward, researchers and policymakers must work to bridge theoretical advancements with actionable strategies, fostering a more connected and policy-relevant research ecosystem. This study contributes to setting a research agenda aimed at refining pricing

methodologies, enhancing collaboration, and aligning weather derivatives with global sustainability and risk mitigation goals.

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