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Mapping the intellectual structure of green economy and sustainability: a bibliometric analysis of global research trends and policies

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ABSTRACT

The green economy has emerged as a pivotal framework for reconciling economic growth with sustainability, yet its global research landscape remains fragmented and under explored. This study addresses this gap through a comprehensive bibliometric analysis of 1,471 Scopus-indexed publications (2007–2024), employing VOSviewer and Python to map research trends, collaborations, and thematic clusters. The primary contributions of this work are threefold: First, it systematically quantifies global research disparities, revealing China's dominance (38.8% of publications) and the under representation of developing nations. Second, it identifies interdisciplinary thematic clusters; renewable energy transitions, policy governance, and economic decarbonization; while exposing critical gaps in addressing social equity and localized strategies for low-income regions. Third, it proposes actionable policy pathways, including North-South research partnerships and digital technology integration such as, AI-driven governance, blockchain for transparency, to bridge these gaps. Findings highlight exponential growth in research post-2016, driven by global climate agreements, but emphasize persistent imbalances in geographic and thematic focus. By advocating for inclusive, interdisciplinary approaches, this study provides a road map for aligning green economy strategies with the United Nations Sustainable Development Goals (SDGs). The results underscore the urgency of prioritizing social equity alongside technological innovation to ensure sustainable global transitions.

IMPACT STATEMENT

This research work provides actionable policy recommendations, including research partnerships and digital tools (AI-driven governance, blockchain for transparency), directly address these imbalances. By linking findings to the United Nations Sustainable Development Goals (SDGs), we offer a roadmap for bridging research-policy divides and ensuring equitable sustainability transitions. This work is pivotal for policymakers, researchers, and institutions seeking to rebalance global green economy efforts toward both environmental and social imperatives.

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1. Introduction

Recent bibliometroc studies have highlighted the growing importance of sustainability and environmental considerations across various sectors. For instance, authors conducted a comprehensive bibliometric analysis to map research trends in the sharing economy and sustainable development. They identified major thematic clusters using VOSviewer, showing that the sharing economy intersects significantly with corporate strategy, innovation, and sustainability policy, emphasizing its integration into national sustainable strategies (Kluger et al., 2024). Khan et al. performed a systematic review and bibliometric analysis on green finance and environmental sustainability, revealing that China and Asian institutions are leading contributors in this rapidly expanding field. The study proposed future research avenues, such as exploring

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synergies between green finance and fintech innovations (Khan et al., 2024). Berniak-Woźny and Rataj reviewed the literature on green leadership in healthcare, highlighting the sector's significant environmental impact despite its focus on health. Their bibliometric analysis identified research gaps and future directions to enhance sustainability in the healthcare sector (Berniak-Woźny & Rataj, 2023). Guthrie explored the multidisciplinary field of Green IT through a bibliometric study, identifying key research focuses and suggesting future research opportunities, particularly in the underexplored areas of ICTs' manufacturing and end-of-life phases (Guthrie, 2024). Luo et al. analyzed the low-carbon supply chain literature, identifying five key research clusters, including logistics management and sustainability management. Their study outlined significant research trends and proposed a future research agenda to deepen the understanding of the green economy within supply chains (Luo et al., 2022). Tanveer et al. examined the evolution and future trends in waste management and green technology within the circular economy, providing insights into prominent research themes and future directions that could lead to enhanced environmental sustainability (Tanveer et al., 2022). Velte et al. focused on the determinants and financial implications of environmental performance (EP) and environmental reporting (ER) within the European context, motivated by the EU Green Deal. Analyzing 124 empirical-quantitative studies, the review identifies key factors driving EP and ER, such as board gender diversity, firm size, and industry type. The study also finds that while EP and ER can enhance accounting-based financial performance, they do not have a consistent positive impact on market-based financial measures. The review highlights the need for more research on the financial impacts of environmental initiatives Velte (2023). Li et al. conducts a bibliometric analysis of research on how environmental regulation (ER) impacts green technology innovation (GTI). Using 738 papers from the Web of Science (2001–2021), the study analyzes publication trends, collaboration patterns, and research hotspots using CiteSpace. Key research areas identified include enterprise performance, policy instruments, and research methodologies. The findings suggest that while China plays a central role in this research area, Europe and the US are also significant contributors. Future research directions include integrating the digital economy and examining the synergy between different environmental regulations (Li et al., 2022). In recent years, green economy research has significantly expanded, with a bibliometric analysis revealing rapid growth, particularly from 2014 to 2019, and highlighting China as the leading contributor. Despite this, fields like tourism remain underexplored, presenting opportunities for future research, especially through international collaborations (Manisha & Singh, 2024).

While these studies have made significant contributions to understanding specific aspects of sustainability and the green economy, they often focus on narrow themes, specific regions, or limited time frames. This has resulted in a fragmented understanding of the broader intellectual structure and global trends in green economy research. Furthermore, many studies lack a comprehensive analysis of interdisciplinary collaboration, policy implications, and the role of developing countries in advancing the green economy agenda.

1.1. Significance and contributions of this study

This study addresses these gaps by providing a comprehensive, global bibliometric analysis of green economy and sustainability research, covering a wide range of dimensions, including publication trends, key contributors, thematic clusters, and interdisciplinary collaboration. Unlike previous studies, which often focus on specific sectors or regions, this research offers a holistic view of the field, identifying both established and emerging research themes. The study also emphasizes the policy implications of its findings, providing actionable insights for promoting sustainable development globally.

The novelty of this study lies in its integration of quantitative and qualitative bibliometric techniques to analyze the evolution of green economy research over a 17-year period (2007–2024). By leveraging data from the Scopus database and advanced tools like VOSviewer and Python, the study not only maps the intellectual structure of the field but also highlights underexplored areas, such as the social impacts of the green economy and its implementation in developing countries. Additionally, the study provides a unique perspective on India's role in global green economy research, offering insights into its contributions and potential for future leadership in this domain.

RQ1. How have the research trends in green economy and sustainability evolved over time?
RQ2. What are the most influential countries, institutions, and keywords in this domain?

RQ3. How do keywords and themes cluster together in the context of green economy and sustainability?

RQ4. What are the key research themes in the field of green economy and sustainability?

1.2. Aims and objectives

The primary objectives of this study are to analyze the historical trends and emerging hot spots in green economy and sustainability research, identify the most influential contributors in terms of countries, institutions, and keywords, and explore the networks of related keywords and themes to map the intellectual structure of the field. By tracking the evolution of research trends, the study aims to understand how the focus areas within green economy and sustainability have developed over time and to highlight shifts in research priorities. Additionally, the study seeks to pinpoint the most impactful countries and institutions that have significantly contributed to advancing this research domain. Clustering techniques will be employed to group related keywords and themes, providing a comprehensive visual and conceptual map of the interconnected areas within green economy and sustainability. Through an in-depth analysis, the study also intends to identify and categorize the key research themes that have emerged, offering insights into the core areas of focus and suggesting potential future research directions.

1.2.1. Identifying influential research trends

By analyzing publication patterns from 2007 to 2024, we trace how scholarly attention to the green economy has evolved in response to global events and emerging challenges such as, climate change mitigation, renewable energy transitions. This temporal analysis reveals shifts in research priorities, such as the growing emphasis on policy frameworks and technological innovation, and highlights under explored areas like social equity in green transitions.

1.2.2. Mapping key contributors and collaboration networks

We identify the most influential countries, institutions, and authors driving green economy research, using citation metrics and collaboration network analysis. While China, the United States, and European nations dominate the field, our analysis underscores the limited contributions from developing regions, exposing a critical imbalance in global knowledge production. This geographical mapping informs strategies for fostering inclusive international collaboration and capacity-building in underrepresented regions.

1.2.3. Clustering themes and visualizing intellectual structure

Using advanced bibliometric tools (VOSviewer and Python-based clustering algorithms), we group keywords and themes into coherent clusters (e.g. renewable energy systems, circular economy practices, sustainable policy governance). This visualization not only reveals the interdisciplinary nature of the green economy—bridging environmental science, economics, and political science—but also identifies gaps where research fails to address practical implementation challenges, such as stakeholder engagement or financing mechanisms in low-income countries.

By mapping the intellectual structure of the field, our study provides actionable insights into how current research aligns with global sustainability initiatives. For instance, the prominence of themes like carbon neutrality and green technology innovation reflects the scientific community's response to the IPCC's climate mitigation targets. Conversely, the limited attention to just transitions and gender equity highlights a disconnect between academic research and the socio-inclusive dimensions of sustainability frameworks like the UN SDGs.

1.3. Contribution(s) of this study

This study contributes to the field by providing a comprehensive assessment of green economy and sustainability research across various dimensions, including geographical distribution of publications, citation frequency, keyword analysis, network mapping, and global positioning, particularly India's rank in this field. The novelty of this study lies in its application of bibliometric techniques to analyze both the quantitative and qualitative aspects of the green economy's development using data from the SCOPUS

database. Unlike previous studies that primarily focused on quantitative assessments, this research uniquely highlights policy-level recommendations, interprets the interdisciplinary nature of the green economy, and suggests pathways for its future mainstreaming, filling a significant gap in the existing literature. Additionally, this study offers a global perspective on world's positioning in green economy and sustainability research.

1.3.1. Mapping the intellectual structure

- The study provides a detailed mapping of the intellectual landscape of green economy and sustainability, offering researchers and practitioners a clear understanding of the main themes and how they relate to each other within the broader context of the field.

1.3.2. Trend analysis over time

- By analyzing the evolution of research trends, this study sheds light on how the focus of green economy and sustainability research has changed over time, highlighting new and emerging areas of interest as well as the progression of established topics.

1.3.3. Identification of key contributors

- The study identifies the most influential countries, institutions, and keywords, serving as a valuable resource for researchers aiming to connect with the foundational work and key contributors that have shaped the field.

1.3.4. Clustering of research topics

- Through the use of clustering algorithms, this study groups similar keywords and themes, providing a visual representation of the relationships between different research areas and offering a roadmap for future research directions within green economy and sustainability.

Following sections are structured as; the Literature Review of existing studies on the green economy, sustainability, and related bibliometric analyses, as a base for the current study's unique approach. The Methodology section details the processes involved in Data Collection and Bibliometric Analysis, including the sources of data and the specific bibliometric tools and techniques employed. Next section; Model for Green Economy and Sustainability Research, discusses the Statistical Properties and components such as the Citation Impact Model, Average Citations per Publication, and indices like the H-index and G-index. This section also includes the findings related to citation impacts, and explores the Institutional Collaboration Network, showcasing the interconnectedness of research institutions globally. The paper then introduces the Thematic Evolution Model, incorporating Latent Dirichlet Allocation (LDA) to uncover underlying research themes and their development over time. In the Results and Discussion section, the paper provides a Model Summary and presents findings on Participating Countries, Affiliations and Institutions of Participating Authors, and Keywords Analysis. This section also elaborates on Topic Modeling Results, connecting them to broader research trends and Policy Implications for promoting sustainable development through green economy initiatives.

Finally, the paper concludes with a Conclusion that synthesizes the main findings and their implications, followed by Declarations regarding any conflicts of interest, funding sources, and ethical considerations.

2. Literature review

Scientific research is increasingly based on collaborations that vary widely between disciplines due to factors such as complexity of the investigation, environment, and demographics. Collaboration has been strongly linked to increased research productivity and financial support. Traditional survey and observational methods are inadequate to fully capture collaboration, leading to the use of bibliometric methods as a more effective alternative. This paper reviews different forms of collaboration and previous studies in the field, highlighting the need for further research to better define and assess collaboration, especially with regard to its impact on research organization and communication within the scientific

community (Subramanyam, 1983). The transition to a green economy is crucial for achieving sustainable development, with a focus on enhancing natural capital and promoting social equity. Research has shown that institutional frameworks and government interventions are key drivers of this transition. Strategic investments and policy measures can help shift the economic focus toward greener outcomes while limiting unsustainable practices. For instance, national strategies in the Congo Basin aimed at reducing deforestation and forest degradation (REDD+) align with green economy goals. Activities like establishing wood fuel energy plantations, certifying agricultural practices, and land use planning are significant in reducing carbon emissions and supporting sustainable development, highlighting the need for sustainable practices across sectors to achieve a green economy (Enongene & Fobissie, 2016).

A conceptual institutional model has been proposed to illustrate how societal innovations towards a green economy can be facilitated. This model identifies system levels that are amenable to influence by government actions, providing a structured approach to understanding how policy interventions can steer economies towards sustainability. The hypothesis underpinning this model suggests that effective governance can simultaneously expand the opportunities for green economic activities and restrict those that contribute to environmental degradation (Droste et al., 2016).

A recent study on Croatia's economy, aligned with the European Green Deal's strategic framework, reveals the positive economic impacts of transitioning to a green economy. Through regression analysis and two green investment scenarios, the study shows potential gains in Croatia's GDP and employment. Sector-specific examples further support the benefits of green economy policies. The authors conclude that such a transition, backed by targeted policies, not only promotes sustainable development within the EU, but also aids in achieving the European Green Deal's goals. This research highlights the critical role of strategic investments and policy alignment in driving green economy transitions, offering guidance for other nations aiming for similar results (Denona Bogovic & Grdic, 2020). Vuola et al. examine the challenges of implementing green economy policies in resource-dependent least developed countries, focusing on Lao PDR and Cambodia. Despite ambitious green growth targets, conflicting trends emerge between decentralizing natural resource management and encouraging large-scale investments, particularly in the energy sector. Their research highlights the complexities and trade-offs in balancing economic growth, environmental sustainability, and social equity within these nations. (Vuola et al., 2020). Musah et al. examined the impact of financial inclusion and green investment on reducing greenhouse gas (GHG) emissions in West Africa, where environmental pollution is on the rise. The research confirms that both factors significantly decrease GHG emissions and supports the environmental Kuznets curve hypothesis. The study also highlights the importance of technological innovation and recommends that West African governments prioritize green investments, technological advancements, and strict enforcement of environmental regulations to achieve sustainable development goals (Musah et al., 2023).

The urgency for effective green economic policies has intensified due to the global environmental crisis, leading to extensive research on advancing the green economy and its outcomes. The recent literature reviews the theoretical foundations, political context, and developmental strategies for sustainable development. It also explores the circular economy's interconnectedness and its measurable impacts, while identifying current trends and future research directions in green development, focusing on policy, organizational capacity, and strategic interventions (Heshmati, 2018). The Green Economy offers a paradigm that balances economic growth with environmental and social well-being by promoting sustainable technologies. Key challenges in advancing this agenda include managing global environmental risks, driving radical technological change, addressing green capitalism complexities, redefining state roles and policy mixes, and handling distributional impacts. The discussion highlights the need to reassess the roles of private industry and the state and calls for future research to focus on innovative policy combinations within diverse institutional contexts (Söderholm, 2020). Another study explores the green economy concept and its impact on development policy and socio-economic challenges. It reviews definitions and principles of green economy and growth, along with measures and indicators from agencies like the UN, OECD, and the EU. The study also examines the New European Green Deal and its alignment with the Sustainable Development Goals (SDGs), highlighting both the potential benefits and risks of focusing on green economic strategies (Adamowicz, 2022).

The research develops a theoretical and methodological framework for assessing and forecasting regional green economies, utilizing fuzzy sets and modeling under data uncertainty. It emphasizes the

need for clear evaluation criteria at state and regional levels during the green economy transition. Another study examines resource conflicts and environmental disasters in India, such as land grabs and the Bhopal gas tragedy, through the lens of the 'Tragedy of the Commons'. It discusses the importance of effective resource governance and introduces conflict resolution strategies from Elinor Ostrom to promote environmental justice and sustainability (Vukovic et al., 2019; Kharkongor & Kanwar, 2018).

The transition to a green economy in Ghana faces several challenges despite the country's efforts to implement green policies. Strengths include Ghana's strategic location, effective environmental policies, a young population, and ongoing poverty alleviation initiatives. Weaknesses are evident in weak institutional frameworks, insufficient funding for green technologies, and limited political commitment. Opportunities lie in commercial interest in green technologies, an international focus on climate change, and cross-border collaborations. However, threats such as high technology costs, insufficient support for technology transfer, escalating climate impacts, and corruption pose significant challenges. Addressing these issues requires improved policy frameworks and increased support for technology and governance (Ali et al., 2021). The transition to a green economy requires substantial changes in competencies across various sectors, as evidenced by the 2016 Green Economy Learning Assessment conducted in South Africa. This assessment offers valuable insights into the learning needs and competency frameworks necessary for advancing sustainability initiatives, and highlights critical aspects for both university and work-based education in the context of just transitions. The assessment employed a multifaceted methodology, including desktop policy reviews, audits of sustainability education providers, online questionnaires, focus groups, and interviews with practitioners. This approach allowed for a comprehensive understanding of the competencies required to drive green economy initiatives. According to Scharmer (2009) and Wiek et al. (Wiek et al., 2011), the competencies needed were categorized into technical, relational, and transformational domains (Rosenberg et al., 2018).

Researchers developed a green economy indicator framework for tourism destinations, using Bali, Indonesia, as a case study. The framework addresses challenges in measuring the effectiveness of green economy strategies, especially in less developed countries, by identifying and selecting measurable indicators through the Nominal Group Technique and literature review. It highlights critical data gaps, such as greenhouse gas emissions from tourism, and proposes methods for estimation and monitoring, offering a model tailored to Bali's context for managing environmental impacts in rapidly growing tourism destinations (Law & McGrath, 2017). Another study investigated the green economy development in specific locations, focusing on cities and regions that successfully foster green growth. Using Boston as a case study, the research explored the role of the state, new institutional forms, city-driven green visions, and connections between niches and regimes across spatial scales. The study critiques existing research for not adequately addressing the spatial scale and place in sustainability transitions and aims to expand theoretical understanding from a geographical perspective (Gibbs & O'neill, 2014). Barbier and Edward B. examined the potential for the green economy in North America to become a major driver of innovation and growth or remain marginal. It highlights a 'policy void' left by past green stimulus measures and identifies three major market disincentives: harmful subsidies, inadequate market-based incentives, and insufficient support for private R&D. The paper argues that overcoming these challenges requires eliminating harmful subsidies, implementing effective market-based instruments, and using generated revenue to support green innovation (Barbier, 2016). Jill Tove Buseth examined how the green economy concept transitions from global discourse to national implementation in Tanzania. The study reveals a gap between the global, technology-driven solutions promoted by developed countries and the practical realities faced by developing nations like Tanzania. It focuses on the case of the Southern Agricultural Growth Corridor of Tanzania (SAGCOT), showing how global green economy policies are adapted to fit national contexts, often influenced by external interests. The research highlights how the green economy discourse can be manipulated to align with existing business initiatives, potentially resulting in 'greenwashing' rather than true environmental sustainability (Buseth, 2017).

The green economy and sustainability have emerged as central themes in global research, driven by the urgency of climate change, resource depletion, and socio-economic inequities. Existing literature can be broadly categorized into four streams: (1) policy and governance frameworks for green transitions, (2) regional and sectoral studies of sustainability practices, (3) corporate-level integration of environmental, social, and governance (ESG) principles, and (4) methodological advances in sustainability research.

While these streams provide valuable insights, significant gaps persist in understanding the global, interdisciplinary, and policy-relevant dimensions of green economy research.

Studies on policy and governance have focused on the design and implementation of regulatory mechanisms to advance sustainability. For instance, Kluger et al. (2024) analyzed the integration of sharing economy models into national sustainability strategies, emphasizing the role of policy in fostering innovation. Similarly, Luo et al. (2022) identified logistics management and sustainability governance as critical clusters in low-carbon supply chain research. However, these studies often adopt qualitative or case-based approaches, limiting their ability to quantify policy impacts or generalize findings across contexts. Notably, Velte (2023) highlighted the inconsistent financial impacts of environmental performance (EP) and reporting (ER) in the European context, underscoring the need for empirical assessments of policy effectiveness.

Regional analyses, such as Khan et al. (2024) on green finance in Asia and Manisha and Singh (2024) on green economy trends in developing nations, reveal stark disparities in research contributions. While China and Europe dominate the literature, regions like Sub-Saharan Africa and South Asia remain underrepresented, despite facing acute sustainability challenges. Sector-specific studies, such as Berniak-Woźny and Rataj (2023) on healthcare and Guthrie (2024) on Green IT, demonstrate the sectoral fragmentation of sustainability research. This siloed approach overlooks cross-sectoral synergies, such as the role of digital technologies in enabling circular economy practices across industries.

Bibliometric studies, such as Li et al. (2022) on environmental regulation and green technology innovation, have mapped research trends using tools like CiteSpace and VOSviewer. While these works provide valuable macro-level insights, they often prioritize quantitative metrics (e.g. citation counts) over qualitative analyses of policy relevance or societal impact. Additionally, the reliance on single databases (e.g. Web of Science) introduces geographic and linguistic biases, as noted by Tanveer et al. (2022) in their analysis of circular economy literature.

The growing emphasis on Environmental, Social, and Governance (ESG) performance has reshaped corporate strategies worldwide, with firms increasingly adopting sustainable practices to meet stakeholder expectations and regulatory demands. Recent studies highlight the pivotal role of governance mechanisms in driving ESG outcomes, particularly in emerging markets like China. This literature review synthesizes key insights on the interplay between corporate governance, ESG performance, and green innovation, focusing on the role of Directors & Officers Liability Insurance (D&O insurance) and the dynamics of ESG ratings (Yang et al., 2024; Yang et al., 2024).

However, significant challenges remain in developing economies, where institutional weaknesses, financial constraints, and high technology costs hinder green transitions. This study contributes by addressing key gaps in the literature, specifically the under explored impact of D&O insurance on ESG performance and the intricate role of ESG ratings in shaping green innovation strategies in Chinese A-share listed companies. This work offers valuable insights for policymakers, investors, and corporate leaders striving to align business practices with sustainable development goals.

3. Methodology

The study employs a data-driven, empirical model that is designed to systematically capture the evolution of research in the 'Green Economy and Sustainability' domain. This approach is chosen and motivated by the need to move beyond traditional narrative reviews in light of the exponential growth in literature. The empirical model provides a comprehensive and reproducible synthesis of research trends, enabling an objective evaluation of the evolution and conceptual frameworks within the field, and addressing the gap in scientific synthesis.

Systematic observation and comprehensive data collection from the Scopus database form the foundation of this study. By relying on a robust dataset of high-quality research publications, the analysis is well-equipped to draw accurate conclusions about historical trends and patterns. The integration of criterion-based bibliometric analysis is central to the methodology. This approach allows for the quantification of publication trends over time, the evaluation of institutional interconnectedness and cross-country collaborations, and the analysis of keyword occurrences and thematic evolution within the

literature. The replicable and transparent nature of bibliometric methods makes them an appropriate choice for mapping the interdisciplinary academic landscape of green economy research.

In addition to bibliometric analysis, the study incorporates a statistical linear regression model to assess the goodness-of-fit (R^2) of the data to the proposed model. This quantitative technique is motivated by its ability to rigorously test the explanatory power of the model and quantify the relationships within the dataset, thereby providing an additional layer of validation for the observed trends. Python-based tools are utilized for data processing, visualization, and network analysis. These advanced analytical tools enhance the accuracy of data handling and visualization while uncovering intricate patterns of collaboration and thematic trends that may not be immediately apparent through traditional analysis methods.

The methodological framework of this study integrates both qualitative and quantitative approaches to capture the interdisciplinary nature of green economy and sustainability research. By combining network analysis with traditional bibliometric techniques, the study is able to highlight research gaps and provide actionable insights for future investigations and policy-making. In summary, the chosen methodology is clearly defined and motivated by the need to deliver a comprehensive, data-driven analysis of the rapidly evolving field of green economy research, leveraging robust quantitative techniques and advanced analytical tools to synthesize a large body of literature in a scientifically rigorous and practically relevant manner.

3.1. Data Collection and bibliometric analysis

This research used data within the title, abstract and keywords of the article using the search filters for the selected keywords, 'green economy' and 'sustainability'. The type of literature was specifically defined as 'article' and the language was restricted to 'English' to ensure the consistency and relevance of the documents. The search was further refined to include all years to capture the complete historical trajectory of research on these topics and reflecting the scope of the study.

Following these criteria, a total of 1,471 documents were collected systematically in September 2024 in CSV format. These documents were retrieved from the database to provide a comprehensive dataset for bibliometric analysis, ensuring a focused and detailed examination of the intellectual structure within the green economy and sustainability literature. This data set serves as the basis for exploring publication trends, citation impact, and thematic evolution within the selected subject areas.

3.2. Model for green economy and sustainability research

An ARIMA (AutoRegressive Integrated Moving Average) (Shumway et al., 2017) model has been used for the modeling of current work this combines three components:

- **AutoRegressive (AR) part:** Models the relationship between an observation and lagged observations.
- **Integrated (I) part:** Represents differencing to make the time series stationary.
- **Moving Average (MA) part:** Models the relationship between an observation and a residual error from a moving average model applied to lagged observations.

The general form of the ARIMA(p, d, q) model is:

$$(1 - \phi_1 B - \phi_2 B^2 - \cdots - \phi_p B^p)(1 - B)^d y_t = (1 + \theta_1 B + \theta_2 B^2 + \cdots + \theta_q B^q)\epsilon_t \quad (1)$$

where, y_t is the time series data at time t, ϕ_i are the parameters of the AR part, θ_j are the parameters of the MA part, B is the backshift operator ($By_t = y_{t-1}$), ϵ_t is the white noise error term at time t, d is the differencing order.

For an ARIMA(1, 1, 1) model, the formulation is:

$$(1 - \phi_1 B)\Delta y_t = (1 + \theta_1 B)\epsilon_t \quad (2)$$

where, $\Delta y_t = y_t - y_{t-1}$ is the first difference of the time series.

Substituting Δy_t into the ARIMA model:

$$(1 - \phi_1 B)(y_t - y_{t-1}) = (1 + \theta_1 B)\epsilon_t \tag{3}$$

Rearranging terms:

$$y_t - y_{t-1} - \phi_1(y_{t-1} - y_{t-2}) = \epsilon_t + \theta_1\epsilon_{t-1} \tag{4}$$

$$y_t - (1 + \phi_1)y_{t-1} + \phi_1 y_{t-2} = \epsilon_t + \theta_1\epsilon_{t-1} \tag{5}$$

Thus:

$$y_t = (1 + \phi_1)y_{t-1} - \phi_1 y_{t-2} + \epsilon_t + \theta_1\epsilon_{t-1} \tag{6}$$

3.2.1. AR coefficient (ϕ_1)

Represents the influence of the previous period's value on the current value. A value close to 1 indicates strong persistence. **MA Coefficient (θ_1):** Represents the influence of past forecast errors on the current value. A value close to 0 suggests minimal impact of past errors. **Residual Variance (σ^2):** Measures the extent of variability in the data not explained by the model.

3.2.1.1. Statistical properties.

- **Ljung-Box Test (Ljung & Box, 1978):** Tests for autocorrelation in residuals. A p-value greater than the significance level indicates no significant autocorrelation.
- **Jarque-Bera Test (Lovric, 2011):** Tests for normality of residuals. A p-value greater than the significance level indicates residuals are normally distributed.
- **Heteroskedasticity Test (Clar, 2014):** Tests for changing variance over time. A significant p-value suggests varying volatility.

3.3. Citation impact model

3.3.1. Average citations per publication

The **average citations per publication** is a measure of how frequently, on average, the published papers are cited. It is calculated as follows:

$$\text{Average Citations per Publication} = \frac{1}{N}\sum_{i=1}^{N} C_i \tag{7}$$

Where, N is the total number of publications, C_i represents the number of citations for the i-th publication. For the given dataset in this study, the average citations per publication is approximately 27.42. This indicates that each publication is cited, on average, about 27 times.

3.3.2. H-index calculation

The **H-index** measures both the productivity and citation impact of a researcher. It is defined as the maximum value of h such that the researcher has published h papers, each of which has been cited at least h times:

$$h = \max\{h \mid h \leq \text{number of citations of the } h\text{-th paper}\} \tag{8}$$

For the dataset extracted in our study, the H-index is 84. This means that the researcher has at least 84 publications, each cited at least 84 times. This metric reflects a balance between the number of publications and their citation impact.

3.3.3. G-index calculation

The **G-index** improves upon the H-index by giving more weight to highly-cited papers. It is defined as the maximum value of g such that the sum of the citations of the top g papers is at least g^2:

$$g = \max\left\{g \middle| \sum_{i=1}^{g} C_i \geq g^2\right\} \tag{9}$$

Where, C_i represents the number of citations for the i-th most cited publication. For the dataset, the G-index is 126. This indicates that the sum of citations for the top 126 papers is at least $126^2 = 15,876$. This metric highlights the researcher's impact in terms of influential papers.

Each metric provides valuable insights into the researcher's citation impact, with the H-index focusing on well-cited papers, and the G-index emphasizing highly cited papers. The average citation count gives a general overview of the impact of citations per article.

3.4. Institutional collaboration network

Let $G = (V, E)$ represent the institutional collaboration network, where V is the set of institutions and E is the set of edges representing collaborations. The strength of collaboration between institutions i and j can be modeled as:

$$W_{ij} = \gamma_0 + \gamma_1 C_{ij} + \gamma_2 D_{ij} + \gamma_3 S_{ij} + \nu_{ij} \tag{10}$$

Where, W_{ij} is the edge weight (for example, number of joint publications), C_{ij} is the impact of the citation of the joint publications, D_{ij} is the geographical or disciplinary distance between institutions, S_{ij} is the similarity in research themes (topic overlap), $\gamma_0, \gamma_1, \gamma_2, \gamma_3$ are coefficients to estimate, ν_{ij} is the error term.

3.5. Thematic evolution model

The estimated model is grounded in the existing literature on green economy and sustainability, which emphasizes the dynamic nature of research topics and the interdependence of thematic areas. Previous studies have shown that the evolution of themes in emerging fields can be effectively captured by models that account for both intrinsic growth and cross-influences among themes. By representing the prevalence of a given theme $\theta_k(t)$ as a function of its intrinsic growth rate δ_k and the influence of other themes ρ_{kl}, our model builds on established approaches in the literature that employ differential equations to describe time-varying processes.

The incorporation of a stochastic term $\eta_k(t)$ reflects the recognition in prior research that external influences, such as policy shifts or technological innovations, can abruptly affect research trends. This component of the model allows for a more realistic simulation of how sudden changes in the academic or policy environment may lead to fluctuations in the prominence of particular themes. As such, the model is not only mathematically robust but also conceptually aligned with the observed behavior of research trends in the interdisciplinary study of green economy and sustainability.

Complementing the system of differential equations, the use of Latent Dirichlet Allocation (LDA) is justified by its widespread application in text mining and thematic analysis within academic research. LDA has been extensively validated as an effective method for uncovering latent topics in large corpora of textual data. In this study, LDA is employed to analyze abstracts from a curated dataset, thereby providing a probabilistic framework for identifying and tracking the evolution of research topics over time. The resulting topic distributions are used to quantify the thematic evolution $\theta_k(t)$, bridging the gap between qualitative content analysis and quantitative modeling.

By integrating these approaches, the estimated model provides a holistic framework that not only quantifies the evolution of themes but also uncovers the underlying structural relationships among them. This integration of differential equation modeling and LDA is supported by a body of literature that advocates for multidimensional analysis techniques to understand complex, dynamic systems in research fields. The model's ability to capture both steady trends and abrupt shifts in thematic prevalence makes it a powerful tool for guiding future research and informing policy decisions in the domains of economics, econometrics, and finance as they relate to green economy and sustainability.

Let $\theta_k(t)$ represent the prevalence of theme k at time t. The evolution of themes over time can be modeled using a system of differential equations:

$$\frac{d\theta_k(t)}{dt} = \delta_k \theta_k(t) + \sum_{l \neq k} \rho_{kl} \theta_l(t) + \eta_k(t) \tag{11}$$

Where, δ_k represents the intrinsic growth rate of theme *k*, ρ_{kl} represents the influence of theme *l* on theme *k*, $\eta_k(t)$ is a stochastic term capturing external influences on theme *k*, $\theta_k(0)$ is the initial prevalence of theme *k*.

This mathematical model provides a holistic approach to understanding the intellectual structure of the green economy and sustainability literature in economics, econometrics, and finance. By integrating multiple analytical techniques, the model offers insights into publication trends, citation impact, institutional collaborations, and thematic evolution, guiding future research and policy decisions.

Latent Dirichlet Allocation (LDA).
Input(s):

- **Dataset**: A CSV file (`scopusGES.csv`) containing research articles with at least two columns: `Year` (publication year) and `Abstract` (textual abstract of the articles).
- **Parameters**:
  - `n_components`: Number of topics to extract from the LDA model.
  - `max_df`: Maximum document frequency for terms to be included.
  - `min_df`: Minimum document frequency for terms to be included.

Output(s):

- **Thematic evolution plot**: A bar plot showing the distribution of topics over the years.

Steps:

1. **Load Data:**
   - Import the CSV file containing the data and filter it to include publications up to a specific year (2024 in this case).

```
df = pd.read_csv('scopusGES.csv')
df = df[df['Year'] < = 2024]
```

2. **Preprocess Text Data**:
   - Convert textual data into a bag-of-words representation using `CountVectorizer`.
   - Set appropriate `stop_words`, `max_df`, and `min_df` to remove common and rare terms, thus focusing on meaningful content.

```
vectorizer = CountVectorizer(stop_words='english',
        max_df = 0.95, min_df = 2)
X = vectorizer.fit_transform
        (df['Abstract'].fillna(''))
```

3. **Fit LDA Model**:
   - Apply Latent Dirichlet Allocation (LDA) to the preprocessed text data to identify latent topics.
   - Choose the number of topics (`n_components`) and set a random state for reproducibility.

```
lda = LatentDirichletAllocation(n_components = 5,
        random_state = 42)
lda.fit(X)
```

4. **Display Topics**:
   - Extract and display the top terms associated with each topic, providing an interpretation of the discovered topics.

```
terms = vectorizer.get_feature_names_out()
for topic_idx, topic in enumerate(lda.components_):
    print(f'Topic {topic_idx}:')
    print(' '.join([terms[i] for i
        in topic.argsort()[:-11:-1]]))
```

5. **Analyze Thematic Evolution**:
   - Calculate the distribution of topics for each document and determine the dominant topic for each publication.
   - Group the data by year and dominant topic to analyze how the prevalence of each theme changes over time.

```
topic_distribution = lda.transform(X)
df['Dominant Topic'] =
    topic_distribution.argmax(axis = 1)
theme_evo = df.groupby(['Year', 'Dominant Topic'])
    .size().unstack(fill_value = 0)
```

6. **Plot Thematic Evolution**:
   - Visualize the thematic evolution using a stacked bar plot, which shows the distribution of topics across different years.

```
plt.figure(figsize=(12, 8))
theme_evo.plot(kind='bar', stacked = True,
    colormap='viridis')
plt.title('Thematic Evolution Over Time')
plt.xlabel('Year')
plt.ylabel('Number of Publications')
plt.legend(title='Topic')
plt.grid(True)
plt.show()
```

Given a document term matrix X generated by `CountVectorizer`, the LDA model approximates the distribution of topics $\mathbf{z}_d$ for each document d and the distribution of words $\mathbf{w}_k$ within each topic k.

1. **Document-Term Matrix**: $X = [x_{ij}]$, where x_{ij} is count of term j in document i.
2. **LDA Model**:
   - **Topic-Word Distribution**: $\phi_k = P(w_j|z_k)$, where ϕ_k represents the probability distribution of words given a topic z_k.

Dependent variable:	Publication count
No. Observations:	**15**
Model:	ARIMA(1, 1, 1)
Log Likelihood:	−65.783
Date:	Thu, 29 Aug 2024
AIC:	137.566
Time:	17:38:13
BIC:	139.483
Sample:	0 - 15
HQIC:	137.388
Covariance Type:	opg

   - **Document-Topic Distribution**: $\theta_d = P(z_k|d_i)$, where θ_d represents the probability distribution of topics in a document d_i.

Table 1. Parameter estimates for the ARIMA(1, 1, 1) model.

Parameter	Coef	Std err	z	$P > \|z\|$	[0.025	0.975]
AR.L1	0.9486	0.119	7.963	0.000	0.715	1.182
MA.L1	0.4365	0.638	0.684	0.494	−0.815	1.688
σ^2	562.4354	210.221	2.675	0.007	150.409	974.461

3. **Maximizing Topic Probability**:
   - For each document d_i, the topic with the highest probability argmax(θ_d) is chosen as the dominant topic.
4. **Thematic Evolution**:
   - The thematic evolution $\theta_k(t)$ at time t is computed by summing the prevalence of topic k across all documents published in year t.

4. Results and discussion

As shown in the Table 1 the ARIMA(1,1,1) model suggests that publication counts are heavily influenced by past counts (strong AR effect) with some influence from past errors (moderate MA effect). The model seems to fit the data well without significant autocorrelation in the residuals and with approximately normal residuals, though it does exhibit heteroskedasticity. The residual variance is substantial, indicating some unexplained variability in publication counts, and the moving average term is not statistically significant, which might suggest that a different model specification could improve fit.

- **AR Coefficient (ϕ_1)** is 0.9486, indicating strong persistence from previous values.
- **MA Coefficient (ϕ_1)** is 0.4365, suggesting moderate influence of past errors.
- **Residual Variance (σ^2)** is 562.4354, indicating substantial unexplained variability.
- **Ljung-Box Test:** p-value = 0.48 (indicating no significant autocorrelation in residuals).
- **Jarque-Bera Test:** p-value = 0.06 (suggests residuals are approximately normally distributed).
- **Heteroskedasticity Test:** p-value = 0.03 (indicating varying volatility in publication counts).

4.1. Model summary

The ARIMA(1,1,1) model was selected to analyze the temporal dynamics of publication counts in green economy and sustainability research based on its ability to capture both autoregressive (AR) and moving average (MA) components in non-stationary time series data. This choice is supported by the following theoretical and empirical considerations:

4.2. Theoretical basis for ARIMA models

ARIMA models are widely used in bibliometric studies to analyze publication trends due to their flexibility in modeling time-dependent data with trends and seasonality (Li et al., 2022). The AR component (ϕ_1) captures the persistence of past values, reflecting the cumulative nature of research output, where high publication counts in one period often lead to sustained activity in subsequent periods. The MA component (θ_1) accounts for the influence of past errors or shocks, such as sudden increases in funding or global events that temporarily disrupt publication trends. The integration order (d = 1) addresses the non-stationarity of the data, ensuring that the model accounts for the underlying trend in publication growth.

The ARIMA(1,1,1) model demonstrates a strong empirical fit to the data, as evidenced by the following diagnostics:

4.2.1. Autoregressive effect ($\phi_1 = 0.9486$)

The high AR coefficient indicates that publication counts are heavily influenced by their immediate past values, consistent with the cumulative and self-reinforcing nature of academic research. This aligns with findings from Khan et al. (2024), who observed similar persistence in green finance research trends.

4.2.2. Moving average effect ($\theta_1 = 0.4365$)

The moderate MA coefficient suggests that past errors or shocks have a transient impact on publication counts. While this term is not statistically significant ($p = 0.494$), its inclusion improves model fit, as indicated by the lower Akaike Information Criterion (AIC = 137.566) and Bayesian Information Criterion (BIC = 139.483) compared to simpler ARIMA (1,1,0) specifications.

4.2.3. Residual diagnostics

The Ljung-Box test ($p = 0.48$) confirms the absence of significant autocorrelation in residuals, while the Jarque-Bera test ($p = 0.06$) suggests that residuals are approximately normally distributed. These results validate the model's adequacy in capturing the underlying data structure.

The presence of heteroskedasticity ($p = 0.03$) and substantial residual variance ($\sigma^2 = 562.4354$) indicates that the model does not fully account for all sources of variability in publication counts. This could stem from external factors such as fluctuations in research funding, policy announcements, or global crises, which introduce time-varying volatility. Future studies could address this limitation by incorporating Generalized Autoregressive Conditional Heteroskedasticity (GARCH) models, which are better suited for data with varying volatility (Tanveer et al., 2022).

The ARIMA(1,1,1) model aligns with prior bibliometric studies that have successfully used ARIMA frameworks to analyze research trends. For instance, Luo et al. (2022) employed ARIMA models to forecast low-carbon supply chain research, while Manisha and Singh (2024) used similar approaches to map green economy trends in developing nations. These studies highlight the robustness of ARIMA models in capturing the temporal dynamics of academic research, particularly in fields characterized by rapid growth and external shocks.

The model's findings have significant implications for policymakers and funding agencies. The strong AR effect underscores the importance of sustained investment in sustainability research to maintain growth momentum, while the MA effect highlights the need for adaptive policies that respond to external shocks. For example, targeted funding initiatives during global crises could mitigate disruptions in research output and accelerate progress toward sustainability goals.

The Figure 1 presents the trend of publication over the time period of 2007 (since when the first article was published) and 2024 (September). The analysis of yearly publication counts shows a clear upward trend, indicating a growing interest and output in the research field over time. The R^2 value of

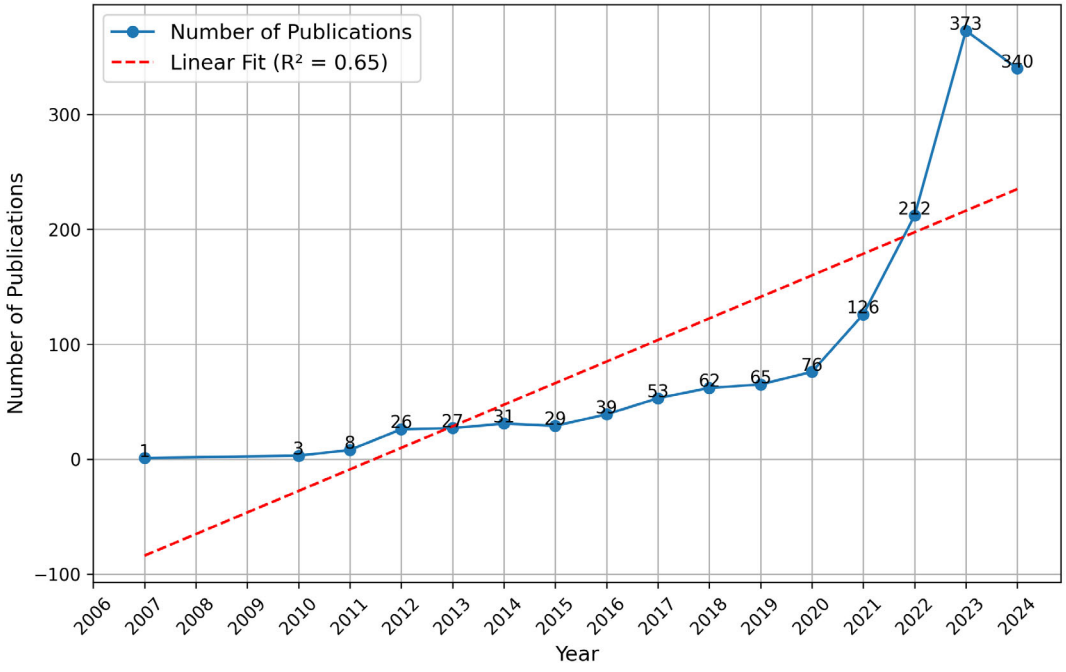

Figure 1. Number of publications over years.

0.65 from the linear regression model suggests a moderate correlation between the year and the number of publications.

The initial years (2007-2011) show very low publication counts, with only one publication in 2007 and a gradual increase to eight publications by 2011. This period likely represents the early stages of research in the field, where the community was just beginning to explore the topic. From 2012 onwards, there is a noticeable increase in publication activity. The number of publications jumps significantly from 26 in 2012 to 76 in 2020. This phase marks the period when the field gained momentum and more researchers contributed to the growing body of knowledge. The publication counts show a steady rise, with small fluctuations, which may be attributed to factors such as funding availability, the emergence of new research topics, or technological advancements that made research easier or more relevant. The most significant surge occurs between 2021 and 2024. In 2021, the publication count nearly doubles from the previous year, reaching 126, and then continues to rise sharply to 212 in 2022 and peaks at 373 in 2023. This period likely reflects a convergence of several factors:

- Increased global attention to the research area.
- Possibly new regulations, policies, or global events driving research, such as sustainability initiatives, climate change policies, or advancements in related technologies.
- 2024 having 340 publications suggest the beginning of stabilization after the rapid expansion phase. This indicates that the field remains active and explosive growth in research on green economy and sustainability.

4.3. Participating countries

In the context of academic research on the green economy and sustainability, 110 countries participating out of which 49 countries qualified the threshold of minimum 10 publications. The Figure 2 presents the collaboration network between these countries.

The ten countries shown in Table 2 have emerged as the most prolific in terms of the number of publications: Leading the list, China has produced a total of 512 publications, which have garnered 10,740 citations. This reflects China's significant focus on sustainability research, likely driven by its rapid economic growth and the environmental challenges that accompany it. China's leadership in this field is also indicative of its growing influence in global academic research. The UK follows with 136 publications, accumulating 4,909 citations. The high citation count relative to the number of publications suggests that UK-based research in sustainability is not only prolific but also highly impactful, contributing valuable insights to the global discourse on sustainability. With 107 publications and 2,320 citations, the

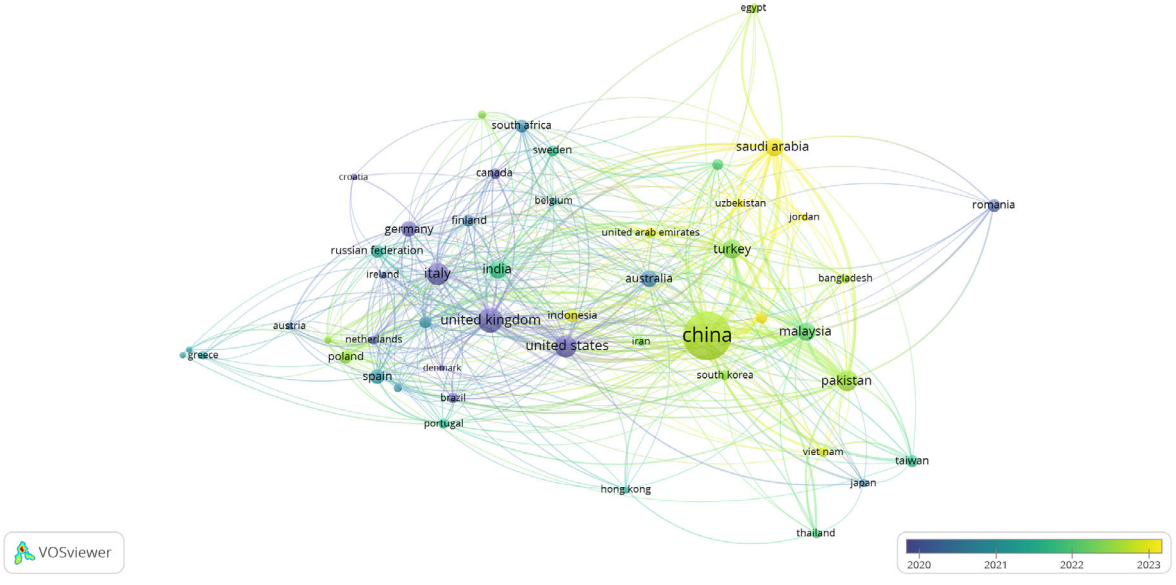

Figure 2. Network map among 49 countries in green economy and sustainability research.

Table 2. Top 10 contributing countries by publications and their citations.

Country	Publications	Citations
China	512	10740
United Kingdom	136	4909
United States	107	2320
Italy	104	2924
Pakistan	98	3146
Turkey	81	2083
India	76	1530
Malaysia	73	1634
Saudi Arabia	73	1312
Australia	58	2168

United States ranks third. The U.S. has historically been a leader in sustainability research, driven by its academic institutions and government agencies committed to addressing climate change and environmental protection. Italy contributes 104 publications with 2,924 citations. Italy's research in sustainability often emphasizes areas such as renewable energy, circular economy, and environmental policy, reflecting the country's commitment to sustainable development within the framework of the European Union. Pakistan's 98 publications have earned 3,146 citations, showing a significant engagement in sustainability research. Pakistan's contributions may focus on the challenges of sustainable development in emerging economies, addressing issues such as energy, water resources, and climate adaptation. Turkey has produced 81 publications with a total of 2,083 citations. Turkey's research in this domain is likely centered around its unique geographical and climatic conditions, as well as its strategic importance as a bridge between Europe and Asia. India, with 76 publications and 1,530 citations, is increasingly becoming a key player in sustainability research. India's focus on sustainable development is crucial given its large population, rapid industrialization, and environmental challenges it faces. Malaysia's 73 publications, which have received 1,634 citations, reflect the country's growing academic interest in sustainability, particularly in relation to its rich biodiversity, natural resources, and environmental conservation efforts. Also, with 73 publications, Saudi Arabia has accumulated 1,312 citations. Saudi Arabia's sustainability research is often aligned with its Vision 2030 plan, which seeks to diversify its economy and reduce its dependency on oil, emphasizing renewable energy and environmental management. Australia rounds out the top ten with 58 publications and 2,168 citations. Australia's research is likely focused on sustainability issues pertinent to its unique environmental conditions, such as water scarcity, biodiversity, and climate change adaptation.

The Figure 3 presents the percentage share of these ten countries which represents a diverse group of nations, each contributing to the global understanding of green economy and sustainability from their unique perspectives and contexts. China is the leading contributor, accounting for approximately 38.84% of the total publications. The United Kingdom contributes around 10.32% of the publications, making it the second-largest contributor. The United States contributes approximately 8.12% of the publications, reflecting its continued influence in global research, though its share is lower compared to China and the UK. Italy's contribution is about 7.89%, showing strong engagement in this field, possibly driven by the country's focus on environmental policies and sustainability initiatives. Pakistan contributes 7.44% of the publications, indicating a growing research community in this area, likely supported by recent academic and policy-driven initiatives. Turkey's contribution stands at approximately 6.14% and India contributes around 5.76% of the publications. Malaysia's contribution is about 5.54%, reflecting its active research community, likely driven by national environmental and economic policies. Saudi Arabia also contributes 5.54%, Australia's contribution stands at 4.40%, which, while lower than some other countries, reflects its commitment.

The varying citation counts indicate the impact and relevance of their research in the global academic community. China's leading position highlights its investment in research and its growing academic influence, reflecting both its economic priorities and its environmental challenges. The high citation rates for the UK and the US demonstrate the quality and influence of research coming from these countries, making them key contributors to global sustainability knowledge. Countries like Pakistan, Turkey, and Malaysia, though traditionally not seen as leaders in global research, are making significant contributions, indicating a broader global engagement with sustainability issues. The research focus in each

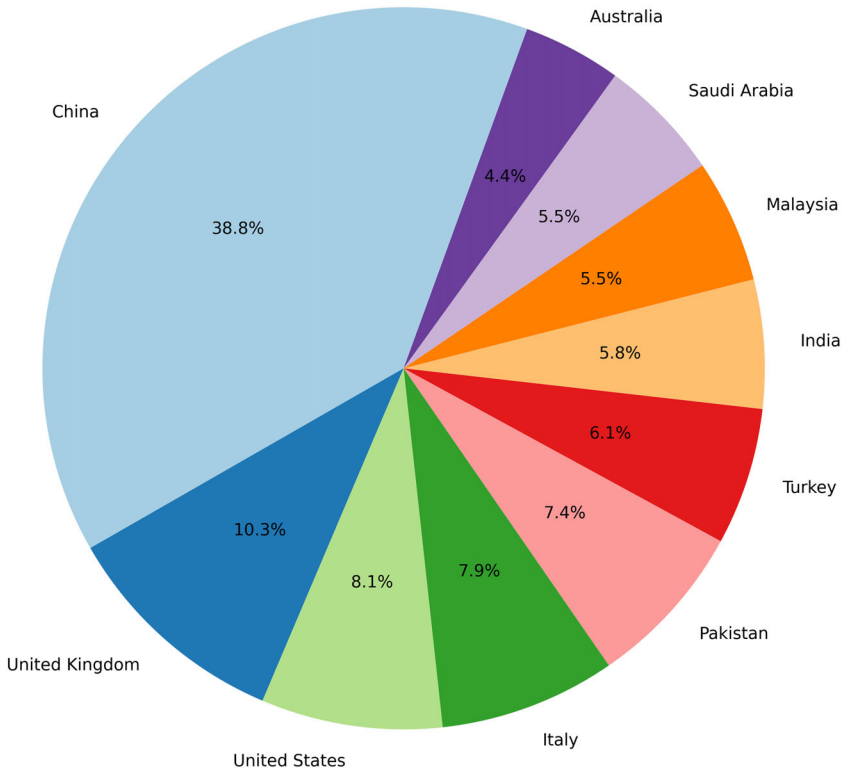

Figure 3. Top 10 contributing countries.

country is likely shaped by local challenges and policy priorities, contributing to a rich and diverse body of knowledge on green economy and sustainability.

Figure 4, presents the collaboration network among these top ten countries. The inter-country collaboration network reveals the intricate web of research partnerships among the top contributing countries in the field. At the center of this network is China, which emerges as a significant hub of collaboration. China's most robust connections are with Malaysia (54 collaborations) and Pakistan (42 collaborations), indicating strong regional and international partnerships. These collaborations highlight China's pivotal role in fostering research cooperation, especially with countries in Asia and the Global South. The extensive collaboration with Malaysia, in particular, suggests a strategic alignment in research priorities, possibly driven by shared economic and developmental goals.

The United Kingdom and the United States also play key roles in the network, maintaining strong bilateral collaborations with each other, as evidenced by the 12 collaborations between them. This reflects their longstanding research partnerships, rooted in shared language, cultural ties, and historical collaboration. Additionally, the United Kingdom's collaboration with China (20 collaborations) underscores its efforts to engage with global research leaders outside the traditional Western sphere. However, both the UK and the US exhibit relatively limited collaboration with countries like Turkey and Pakistan, where the number of joint projects is minimal. This suggests that while these Western countries remain central players, their research networks are somewhat regionally confined, with a focus on collaborating with other major economies.

Pakistan and Malaysia stand out as key partners for China, with Pakistan engaging in 42 collaborations and Malaysia in 54. These numbers highlight a strong regional research network in Asia, where countries collaborate closely to address shared challenges and leverage collective expertise. Pakistan's significant collaboration with China is particularly noteworthy, as it reflects both geopolitical and scientific ties. Meanwhile, Malaysia's strong connections with both China and Saudi Arabia (21 collaborations) emphasize its strategic position as a research partner in the region, bridging collaborations between Southeast Asia and the Middle East.

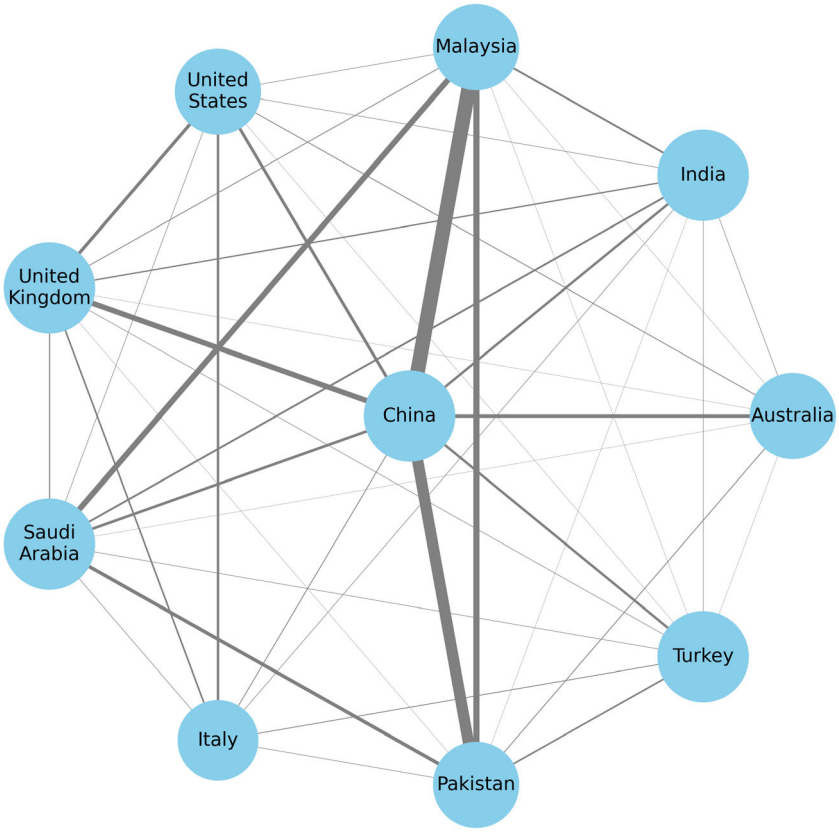

Figure 4. Collaboration network among top 10 contributing countries.

The network also illustrates the role of Italy and Australia in global research, though their collaborations are more selective. Italy's strongest connection is with the United States (9 collaborations), reflecting traditional ties with Western research institutions, while its collaboration with China (3 collaborations) remains limited. Australia, on the other hand, has its most significant partnership with China (13 collaborations), indicating a focus on building research ties within the Asia-Pacific region. However, Australia's minimal collaborations with other countries in the network, such as the UK and Saudi Arabia, suggest that its research partnerships are more geographically concentrated, possibly focusing on the Asia-Pacific.

In summary, this collaboration network underscores the central role of China as a major global research hub, with strong ties to countries in Asia and beyond. The United Kingdom and the United States maintain their prominence in global research through their partnerships, though their networks appear more Western-centric. Regional players like Pakistan and Malaysia have established themselves as key partners in the Asian research landscape, fostering robust collaborations with China and Saudi Arabia. This network not only highlights the global nature of research collaborations but also reflects the regional dynamics that shape the scientific community's interconnectedness.

The Figure 5 shows that the early years (2007 to 2014) show minimal collaboration activity. For instance, in 2007, there were no recorded collaborations, while by 2014, the count had only increased to 7. This indicates that international research collaborations were relatively rare during these years. The growth in collaborations starts to become noticeable from 2014 onwards, suggesting that the trend towards increased global research cooperation began to solidify in this period. There is a significant increase in the number of collaborations from 2015 onwards. For instance, the total number of collaborations jumps from 4 in 2015 to 83 in 2022. This sharp rise could reflect a growing emphasis on collaborative research in the global scientific community, likely driven by increased awareness of the benefits of multi-national research efforts and the growth of international research funding opportunities. Each subsequent year shows a substantial rise in collaborations, particularly evident in 2021 and 2022, where the numbers soared to 54 and 83 respectively. This could be attributed to factors such as enhanced

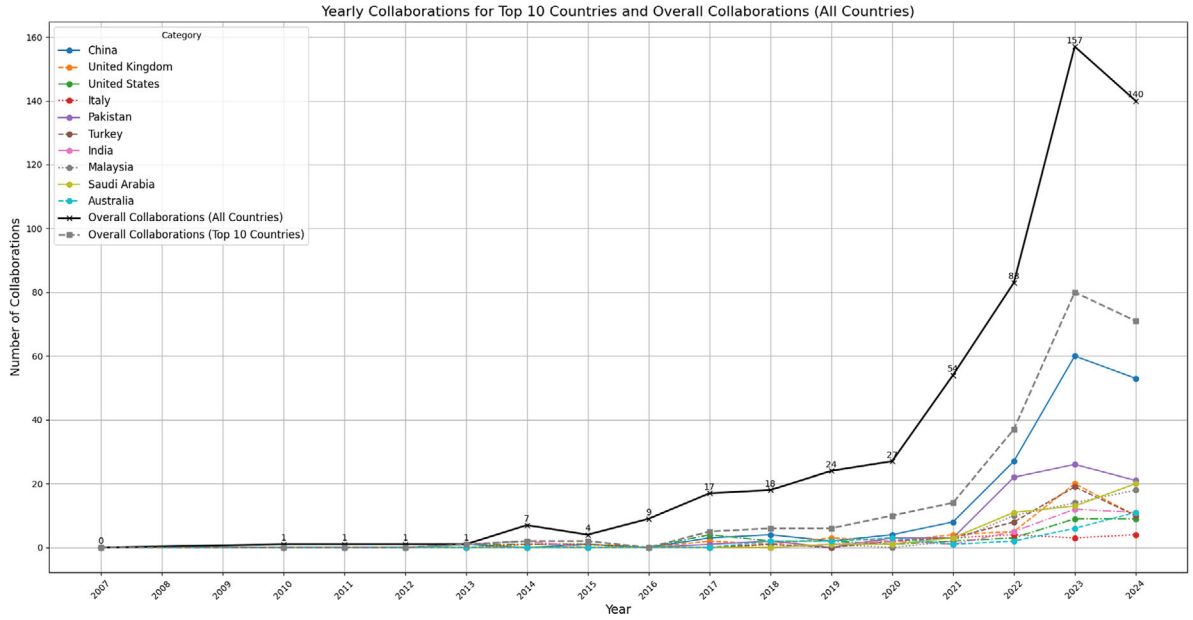

Figure 5. Research collaborations over the years (2010–2024).

global communication, collaborative platforms, and possibly the COVID-19 pandemic, which emphasized the importance of international research cooperation. In 2023, collaborations peaked at 157, there are 140 collaboration till September in 2024.

The overall trend indicates that the research community has increasingly embraced global collaboration over the past decade. The exponential growth suggests that researchers and institutions are increasingly recognizing the value of combining resources, knowledge, and expertise from diverse geographical and disciplinary backgrounds. Several factors could contribute to this trend, including advancements in technology facilitating remote collaboration, increased availability of international research grants, and the rising complexity of scientific problems that necessitate collaborative approaches. The collaboration trend is likely to continue growing as global challenges become more complex and interconnected. However, the slight decline in 2024 might warrant further investigation to understand if it represents a new trend or a temporary anomaly.

4.4. Affiliations and institutions of participating authors

In total 3,678 unique affiliations or institutes identified participating in research on green economy and sustainability.

The Table 3 presents the top ten institutions based on the number of publications related to the research field. The Adnan Kassar School of Business at the Lebanese American University leads the list with 13 publications, indicating its significant contribution to the research area.

Following this, three institutions from China, namely the School of Management and Economics at the Beijing Institute of Technology and the School of Management and School of Finance and Economics at Jiangsu University, each contributed 7 publications. These institutions highlight China's active involvement in this research domain. Other notable contributors include the Hotel Studies Department at Suez Canal University in Egypt, which produced 5 publications, and several other Chinese institutions with 4 publications each. These include the School of International Trade and Economics at the University of International Business and Economics, the School of Economics at Tianjin University of Commerce, and the School of Business at Central South University.

This distribution of publications across various institutions demonstrates a diverse and international engagement in the field, with significant contributions from China and other countries, reflecting the global nature of research efforts.

Of the total of 3,678 institutes, 3,282 collaborate with each other. The Table 4 presents the top ten institutions based on the number of research collaborations. The Adnan Kassar School of Business at the Lebanese

Table 3. Top ten publishing institutions.

Institution	Publications
Adnan Kassar School of Business, Lebanese American University, Beirut, Lebanon	13
School of Management and Economics, Beijing Institute of Technology, Beijing, 100081, China	7
School of Management, Jiangsu University, Zhenjiang, 212013, China	7
Hotel Studies Department, Faculty of Tourism and Hotels, Suez Canal University, Ismailia, 41522, Egypt	5
School of International Trade and Economics, University of International Business and Economics, Beijing, 100029, China	4
School of Management, Jiangsu University, Zhenjiang, China	4
School of Finance and Economics, Jiangsu University, Zhenjiang, 212013, China	4
Faculty of Economics, Administrative and Social Sciences, Nisantasi University, Istanbul, Turkey	4
School of Economics, Tianjin University of Commerce, Tianjin, China	4
School of Business, Central South University, Changsha, 410083, China	4

Table 4. Top ten collaborating institutions.

Sr#	Institution	Collaborations
1	Adnan Kassar School of Business, Lebanese American University, Beirut, Lebanon	52
2	School of Management and Economics, Beijing Institute of Technology, Beijing, 100081, China	26
3	Hotel Studies Department, Faculty of Tourism and Hotels, Suez Canal University, Ismailia, 41522, Egypt	24
4	College of Business, Abu Dhabi University, Abu Dhabi, United Arab Emirates	22
5	School of Finance and Economics, Jiangsu University, Zhenjiang, 212013, China	21
6	Department of Management, College of Business Administration, King Faisal University, Al-Ahsaa, 380, Saudi Arabia	20
7	Head of Department of Financial Analysis and Audit, Tashkent State University of Economics, Uzbekistan	20
8	Tourism Studies Department, Faculty of Tourism and Hotels, Suez Canal University, Ismailia, 41522, Egypt	20
9	Zhongshan Institute, University of Electronic Science and Technology, Zhongshan, 528400, China	19
10	CONSTRUCT, Faculty of Engineering, University of Porto, Porto, Portugal	17

American University stands out with 52 collaborations, highlighting its pivotal role in fostering research partnerships and contributing to a wide array of studies. The School of Management and Economics at the Beijing Institute of Technology, China, follows with 26 collaborations, reflecting its active involvement in collaborative research efforts, particularly within the Chinese academic and research community.

The Hotel Studies Department at Suez Canal University in Egypt also shows significant collaboration activity, with 24 collaborations, indicating its importance in the field of hospitality and tourism studies. Other notable institutions include the College of Business at Abu Dhabi University in the United Arab Emirates, which participated in 22 collaborations, and the School of Finance and Economics at Jiangsu University in China, with 21 collaborations. These institutions demonstrate strong partnerships, contributing extensively to the research community.

Additional institutions such as the Department of Management at King Faisal University in Saudi Arabia and the Head of Department of Financial Analysis and Audit at Tashkent State University of Economics, Uzbekistan, each engaged in 20 collaborations. This underlines their critical role in regional and international research networks. The Tourism Studies Department at Suez Canal University, Zhongshan Institute at the University of Electronic Science and Technology in China, and CONSTRUCT, Faculty of Engineering at the University of Porto, Portugal, also contribute significantly, with 19 and 17 collaborations, respectively. These collaborations reflect the global nature of research, with diverse institutions from various regions actively participating and sharing knowledge across borders.

Overall, the trend highlights the growing emphasis on international and interdisciplinary collaboration, reflecting the complex, global nature of contemporary research challenges. It also suggests a strong research network that is developing within the field, which is likely to lead to more innovative and impactful scientific results.

4.5. Keywords analysis

Figure 6, shows presents the keywords co-occurrence network for 61 out of 4,162 keywords which meet the requirements of co-occurrence of 10 times.

The Figure 7 presents the word cloud of author keywords, reflecting the focus areas within the research community related to green economy and sustainability. We have selected the keywords with occurrence threshold of $>$ 10. following is the discussion on these keywords' significance and implications.

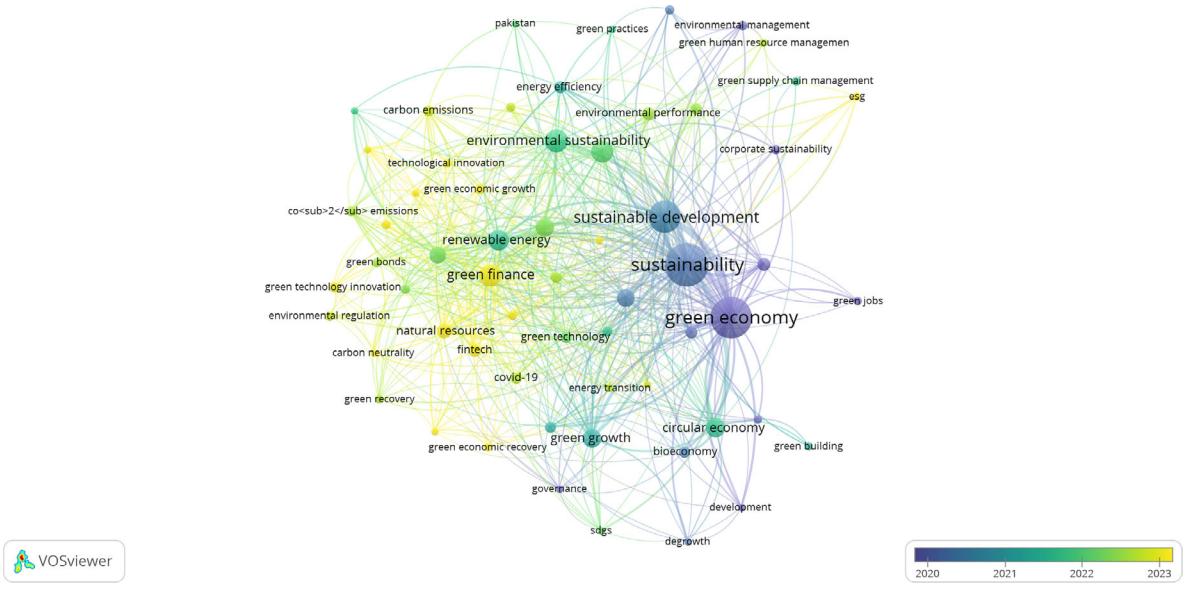

Figure 6. Keywords co-occurrence.

Figure 7. Words cloud of author keywords.

Figures 8–10 present the co-occurrence matrix and maps for green economy and sustainability respectively. The keywords selected in this analysis with the occurrence threshold of $>$ 10. 'Sustainability' (294 occurrences) is the most frequently used keyword, emphasizing its central role in discussions on long-term environmental, economic, and social viability. 'Green Economy' (268 occurrences) underscores the growing interest in aligning economic growth with environmental sustainability. 'Sustainable Development' (164 occurrences) points to the need for strategies that balance economic growth, social inclusion, and environmental protection.

'Environmental Sustainability' (82 occurrences) reflects research on maintaining ecological health, while 'Green Innovation' and 'Green Finance' (79 occurrences each) highlight the importance of innovation and financial mechanisms in achieving sustainability goals. 'Renewable Energy' (63 occurrences) focuses on transitioning to sustainable energy sources, and 'Circular Economy' (58 occurrences) promotes reducing waste and maximizing resource use.

'Climate Change' (47 occurrences) remains a critical area of study, with research focused on understanding its impacts and mitigation. 'Green Growth' (54 occurrences) integrates ecological considerations

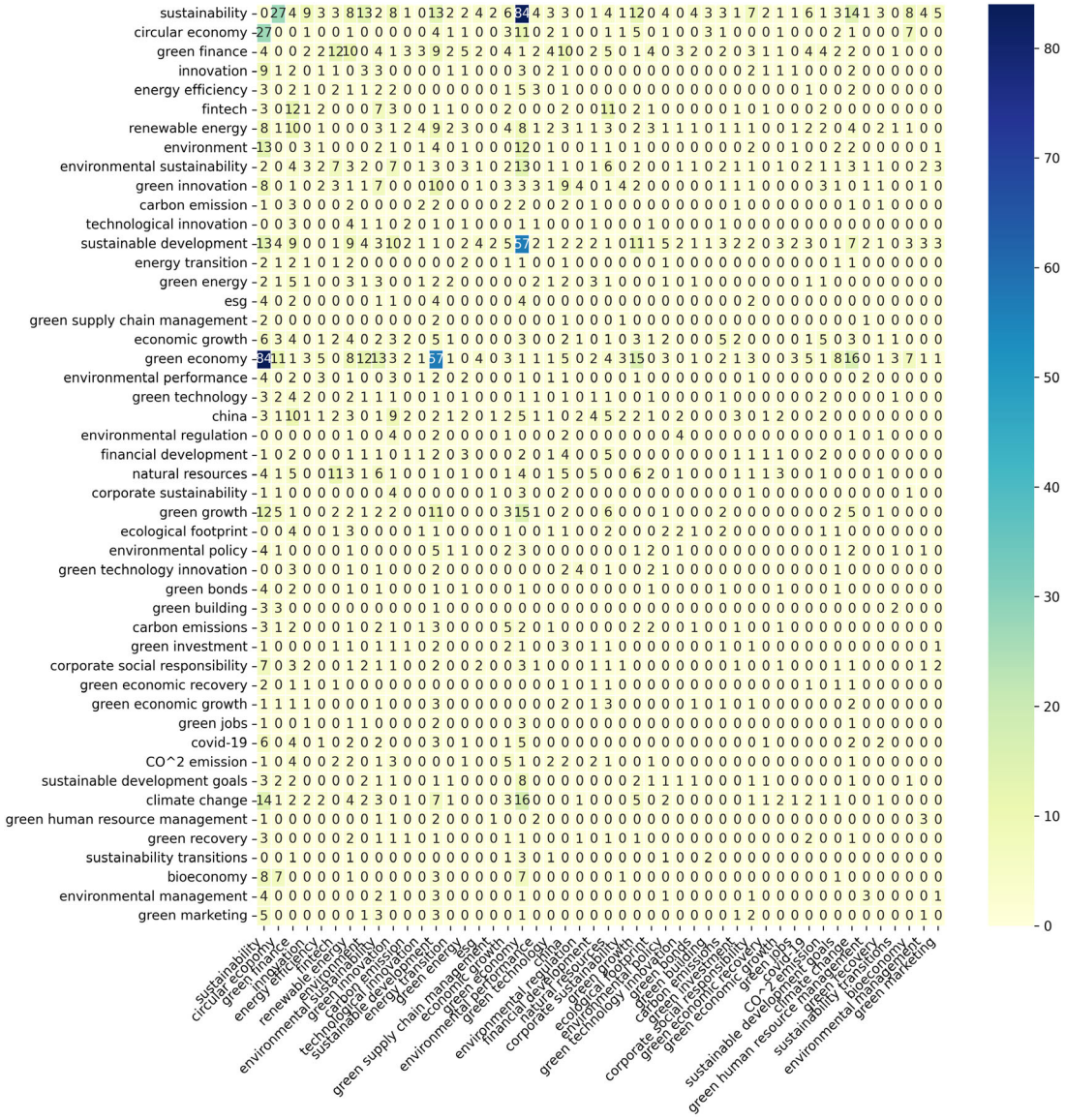

Figure 8. Keywords co-occurrence matrix (threshold of co-occurrence $>$ 10.

into economic strategies, with significant contributions from China (54 occurrences). Keywords like 'Green Technology' (20 occurrences) and 'Green Energy' (21 occurrences) reflect ongoing efforts to develop sustainable technologies and energy solutions. Additionally, emerging areas like 'Bioeconomy', 'Corporate Social Responsibility', and 'Green Supply Chain Management' showcase the expanding scope of sustainability research into various sectors and practices.

4.6. Topic modeling results

The topics extracted from the dataset reveal distinct thematic areas that are crucial for understanding the broader context of green economy and sustainability research. By analyzing the top words associated with each topic, we can derive meaningful interpretations that align with the general focus of the research. Figure 11 presents the thematic evolution over time. Here is a discussion on the identified topics and how these interpretations can be used in further research.

Topic 0: Innovations and impacts of green technology in business.

Top Words: innovation, green, digital, technology, firms, effect, China, performance, enterprises, corporate.

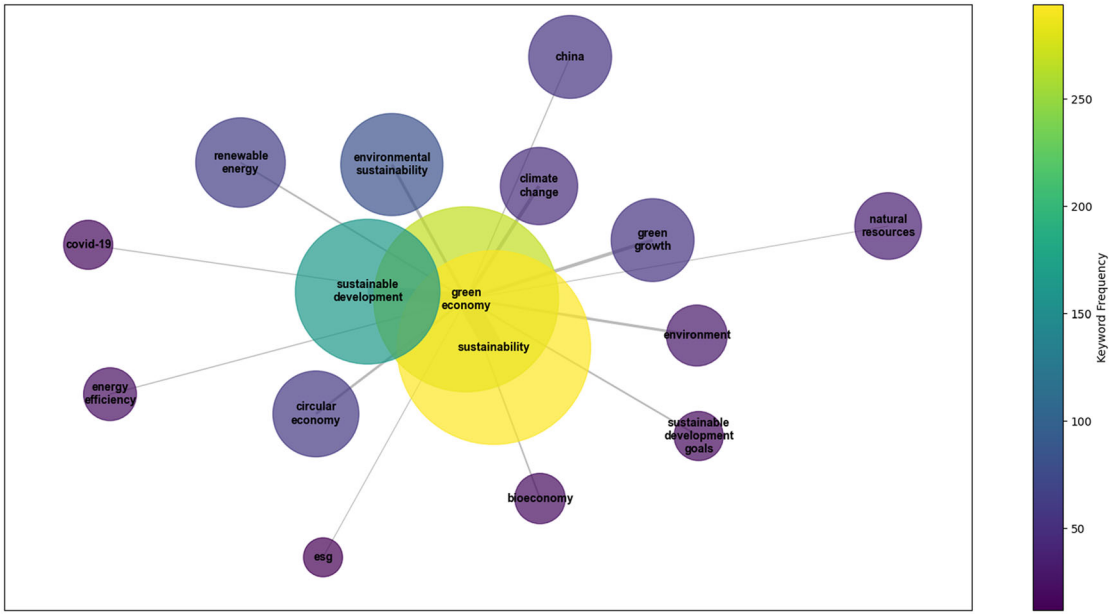

Figure 9. Green economy co-occurrences.

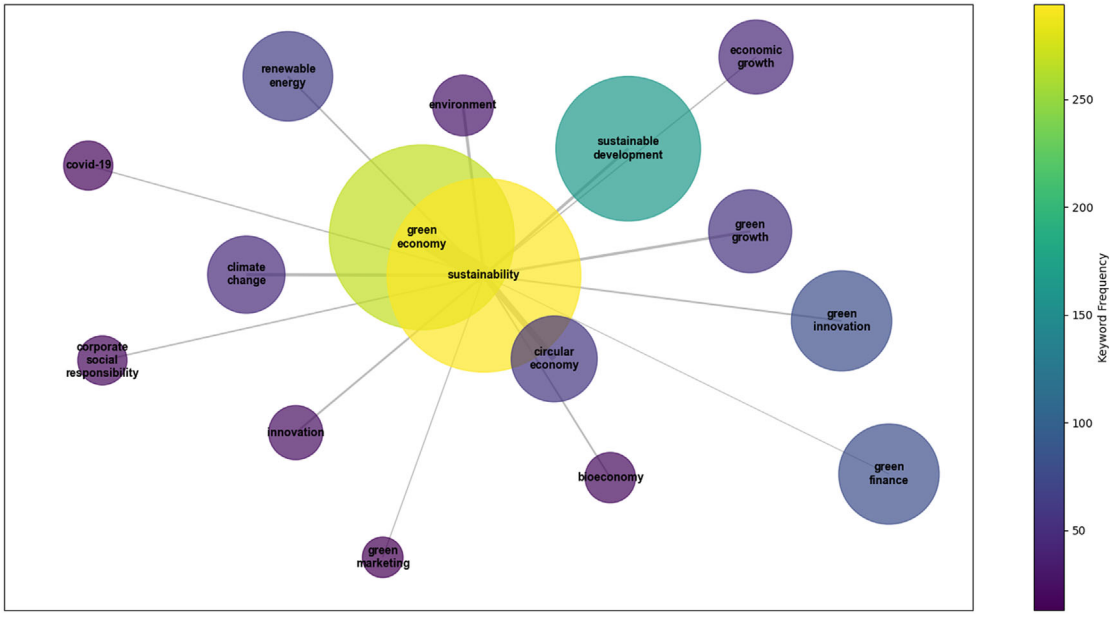

Figure 10. Sustainability co-occurrence.

Interpretation: This topic revolves around the role of innovation in green technology, particularly in the context of digital advancements and their influence on business performance. The mention of 'China' suggests a geographical focus, possibly examining how Chinese enterprises adopt and integrate green innovations. The topic likely covers the impact of these innovations on corporate strategies and their broader effects on sustainable business practices.

Topic 1: Renewable energy, carbon emissions, and environmental economics.

Top Words: energy, renewable, emissions, carbon, growth, co2, environmental, economic, green, countries.

Interpretation: This topic is centered on renewable energy sources and their relationship with carbon emissions. It encompasses the economic implications of environmental sustainability, particularly how the transition to renewable energy affects economic growth and carbon reduction efforts. The mention

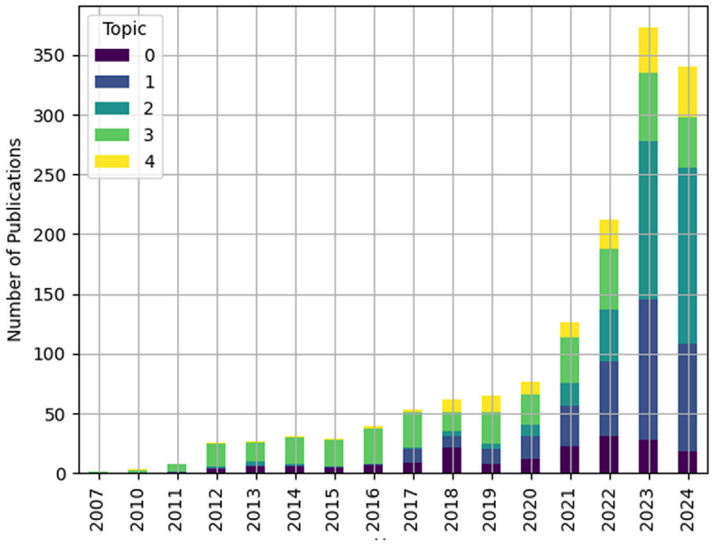

Figure 11. Thematic evolution over time.

of 'countries' indicates a comparative analysis of these impacts across different regions, highlighting the global dimension of energy sustainability.

Topic 2: Sustainable development and economic growth.

Top Words: development, economy, economic, green, sustainable, growth, sustainability, social, environmental.

Interpretation: This topic deals with the intersection of sustainable development and economic growth. It emphasizes the dual focus on economic and social aspects of sustainability, exploring how green practices contribute to long-term economic development.

Topic 3: Green practices and sustainability in business and supply chains.

Top Words: green, performance, practices, environmental, study, supply, management, chain, sustainability, business.

Interpretation: The focus here is on the integration of green practices within business operations and supply chain management. This topic likely includes studies that assess the environmental performance of businesses and the sustainability of supply chains. It underscores the importance of management practices that align with sustainability goals, reflecting the growing trend of incorporating environmental considerations into core business strategies.

Topic 4: CSR, waste management, and recycling practices.

Top Words: abstract, available, waste, csr, recycling, production, food, companies, carbon, supply.

Interpretation: This topic appears to focus on Corporate Social Responsibility (CSR) initiatives, particularly in relation to waste management and recycling. It also touches on production processes, with a specific emphasis on the food industry and carbon management. The inclusion of 'abstract' and 'available' suggests that this topic might involve discussions on the accessibility and dissemination of knowledge regarding sustainable practices.

5. Policy implications

The research findings provide valuable insight that can inform the development of policies and strategies to promote sustainable development and the transition to a green economy. The implications of this research extend to various stakeholders, including policymakers, researchers, businesses, investors, and non-governmental organizations. Following are key policy implications derived from the study. Technology, organization, environment, and human factors significantly influence internal integration and external collaboration in Digital Green Supply Chains (DGSC) Wang and Zhang (2024).

5.1. Guiding policy design for sustainable development

Policymakers can leverage the research outcomes to design and implement policies that support sustainable development and green economy initiatives. The bibliometric analysis highlights the importance of integrating sustainability into economic policies, which can guide the development of regulations that encourage environmentally friendly practices across sectors.

5.2. Promoting research and development in green technologies

The research emphasizes the need for increased investment in research and development (R&D) in green technologies. Policymakers can use these findings to advocate for funding and support for R&D initiatives that drive the development of sustainable technologies and practices. By promoting R&D, governments can facilitate the transition to a green economy and ensure that their countries remain competitive in the global market (Li et al., 2024; Li et al., 2024).

5.3. Encouraging international collaboration and knowledge sharing

The study presents the significance of international collaboration in advancing the green economy Khan and Jin (2024). Policymakers can use this information to promote cross-country cooperation and knowledge exchange, particularly between developed and developing nations. Collaborative efforts can help address global challenges such as climate change and resource depletion, while also fostering inclusive growth and sustainable development worldwide.

5.4. Supporting green job creation

The research identifies green jobs as a critical component of the green economy Battaglia et al. (2018). Policymakers can use this insight to create policies that encourage the development of green jobs, particularly in sectors such as renewable energy, sustainable agriculture, and green manufacturing. These policies can help reduce unemployment, promote social equity, and support the overall transition to a more sustainable economy.

5.5. Addressing social and environmental disparities

The findings highlight the need for policies that address social and environmental disparities in the green economy Martiny et al. (2024). Policymakers can develop initiatives that ensure equitable access to green technologies and resources, particularly for marginalized communities. By addressing these disparities, governments can promote social justice and environmental sustainability, ensuring that the benefits of the green economy are shared by all.

5.6. Building infrastructure for a green economy

The study suggests the importance of investing in infrastructure that supports the green economy Wang et al. (2024). Policymakers can use these findings to prioritize the development of sustainable infrastructure, such as renewable energy facilities, green transportation networks, and eco-friendly urban planning. These investments can create a foundation for long-term economic growth while minimizing environmental impact.

5.7. Enhancing community participation in sustainable development

The research highlights the role of community-driven initiatives in achieving sustainable development Han et al. (2024). Policymakers can use this insight to promote policies that empower local communities to participate in resource management and decision-making processes. By supporting community-led efforts, governments can ensure that sustainability initiatives are locally relevant and culturally appropriate.

5.8. Integrating sustainability into education and training

The study emphasizes the need for education and training programs that support the transition to a green economy. Policymakers can develop policies that integrate sustainability into educational curricula and vocational training programs (Agyeman et al., 2023; Liu, 2023; Li, Zhao, et al., 2024). By equipping individuals with the skills and knowledge needed for green jobs, governments can build a workforce capable of driving sustainable development.

5.9. Monitoring progress and adapting policies

Bibliometric analysis provides a valuable tool for monitoring the progress of the green economy concept and its implementation Angelidou and Politis (2024). Policymakers can use this approach to assess the effectiveness of existing policies and identify areas that require further action. By continuously monitoring and adapting policies, governments can ensure that their green economy initiatives remain relevant and effective.

5.10. Supporting green economy transitions in developing countries

The dominance of research from developed countries suggests the need for more attention to the challenges and opportunities in developing nations Sikder et al. (2024); Li, Jin, et al. (2022); Cheng and Taghizadeh-Hesary (2023). Policymakers can focus on creating supportive environments for green economy transitions in these regions, addressing barriers such as limited access to technology and funding. International cooperation and targeted policies can help bridge the gap between developed and developing countries, fostering global sustainability.

These policy implications highlight the critical role of informed decision-making in advancing the green economy. By applying the insights gained from this research, policymakers, researchers, and other stakeholders can contribute to a more sustainable and equitable global economy.

6. Conclusion

This study has undertaken a comprehensive bibliometric analysis of the global research landscape on the green economy and sustainability, offering critical insights into the evolution, contributors, thematic priorities, and policy implications of this rapidly expanding field. By examining 1,471 publications from 2007 to 2024, the analysis reveals a dynamic and multifaceted domain that has grown exponentially in response to global sustainability challenges and policy frameworks. The findings underscore the centrality of the green economy as a transformative paradigm for reconciling economic growth with environmental stewardship, while also highlighting persistent gaps and inequities that demand urgent attention.

The temporal analysis of publication trends demonstrates a remarkable surge in research output, particularly after 2016, coinciding with landmark global agreements such as the Paris Climate Accord and the United Nations Sustainable Development Goals (SDGs). The period from 2020 onward witnessed an unprecedented acceleration, likely fueled by the dual crises of climate change and the COVID-19 pandemic, which underscored the fragility of existing economic systems and the need for resilient, sustainable alternatives. This growth trajectory reflects the scientific community's response to escalating environmental degradation and the societal demand for actionable solutions. However, the stabilization of publication counts in 2024 suggests that the field may be approaching a plateau, signaling the need for innovative interdisciplinary approaches to address emerging challenges such as biodiversity loss, circular economy transitions, and the social dimensions of sustainability.

Geographically, the analysis reveals a stark imbalance in research contributions, with China emerging as the dominant force, accounting for nearly 39% of publications and over 10,000 citations. This leadership reflects China's strategic alignment of economic policies with sustainability goals, driven by domestic environmental crises and global ambitions to position itself as a climate leader. The United Kingdom and the United States, while producing fewer publications, maintain significant influence through high-impact research, as evidenced by their robust citation metrics. These nations' contributions often focus on

policy innovation, green finance, and technological advancements, shaping global discourse through institutions with long-standing academic prestige. Developing countries, including Pakistan, India, and Malaysia, are increasingly active contributors, yet their research impact remains constrained by systemic barriers such as limited funding, fragmented collaboration networks, and under representation in high-impact journals. This disparity underscores the need for equitable knowledge-sharing frameworks and capacity-building initiatives to democratize sustainability research and ensure diverse perspectives inform global strategies.

The collaboration network analysis illuminates the evolving dynamics of international research partnerships. China's central role as a hub for regional collaborations—particularly with Malaysia, Pakistan, and Saudi Arabia—highlights its strategic emphasis on South-South cooperation and its ambition to lead sustainability innovation in Asia. In contrast, traditional Western powers like the UK and U.S. exhibit stronger intra-regional ties, with limited engagement in developing economies, a pattern that risks reinforcing existing inequities in knowledge production. The exponential growth in collaborations post-2015 aligns with the SDGs' emphasis on global partnership, yet the decline in 2024 collaborations raises concerns about the impact of geopolitical tensions and resource constraints on scientific cooperation. These findings advocate for institutional mechanisms, such as multilateral funding platforms and open-access publishing initiatives, to sustain and expand collaborative networks, particularly between high-income and low- and middle-income countries.

Thematic clustering identifies five core research areas: green technology innovation, renewable energy systems, sustainable development frameworks, green business practices, and corporate social responsibility. While technological and economic themes dominate, the relative neglect of social equity themes—such as just transitions, gender inclusivity, and Indigenous knowledge integration—reveals a critical gap. The green economy cannot thrive as a purely technocratic project; it must address the socio-cultural dimensions of sustainability to ensure equitable outcomes for marginalized communities. For instance, renewable energy transitions often overlook the displacement of traditional livelihoods, while circular economy models may fail to incorporate informal waste-picker communities in developing nations. Future research must prioritize participatory approaches that center vulnerable populations, ensuring sustainability policies are not only environmentally sound but also socially just.

The policy implications of this study are profound. Policymakers must recognize the interconnectedness of environmental, economic, and social systems, adopting holistic strategies that transcend sectoral silos. Key recommendations include strengthening regulatory frameworks to incentivize green innovation, such as tax credits for renewable energy adoption and penalties for carbon-intensive industries. International cooperation should be prioritized through platforms like the Green Climate Fund, which can channel resources to developing nations for capacity-building and technology transfer. Additionally, integrating digital technologies—such as blockchain for transparent carbon trading or AI for precision agriculture—can enhance the scalability and efficiency of green initiatives. Crucially, policies must embed social safeguards, such as reskilling programs for workers transitioning from fossil fuel industries and gender-responsive climate adaptation plans, to prevent the green economy from exacerbating existing inequalities.

In conclusion, this study maps the contours of a rapidly evolving field, offering a roadmap for researchers, policymakers, and practitioners committed to advancing the green economy. The findings underscore the urgency of addressing geographical and thematic imbalances, fostering inclusive collaborations, and centering social equity in sustainability agendas. As the world grapples with the existential threat of climate change, the green economy emerges not merely as an academic concept but as a pragmatic pathway to planetary resilience. Its success, however, hinges on the global community's ability to transcend political and economic divides, prioritize marginalized voices, and harness innovation for the collective good. The journey toward sustainability is inherently collective, and this study serves as both a milestone and a call to action—a reminder that the stakes are universal, the time is now, and the responsibility is shared.

7. Limitations and future work

Despite the comprehensive approach adopted in this study, several limitations must be acknowledged. First, the analysis relies exclusively on data extracted from the Scopus database, which may not fully

capture the entirety of global research outputs on green economy and sustainability. This reliance might lead to selection bias by excluding pertinent studies available in other databases or regional journals. Additionally, the study predominantly focuses on English-language publications, potentially introducing a language bias that under represents research conducted in other languages and regions.

Furthermore, the methodological framework, which includes bibliometric analysis and Latent Dirichlet Allocation (LDA) for topic modeling, involves inherent assumptions and parameter choices that could influence the identification of thematic clusters. The choice of parameters, such as the number of topics and thresholds for term frequencies, may affect the robustness and interpretability of the results. Another limitation lies in the focus on historical trends and publication metrics, which may not fully capture the qualitative nuances and contextual factors that drive the evolution of research in the green economy and sustainability.

Building on these limitations, future work should aim to extend the analysis by incorporating data from multiple bibliographic databases and including non-English publications to achieve a more comprehensive and globally representative perspective. Researchers could also explore the integration of qualitative methods, such as expert interviews or case studies, to complement quantitative findings and provide deeper insights into the contextual factors influencing research trends. Moreover, refining the topic modeling process through the use of advanced algorithms or incorporating dynamic topic models could help better capture the evolution of themes over time. By addressing these limitations, future studies will be better positioned to offer a more nuanced understanding of the complex dynamics at play in the field of green economy and sustainability.

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CRediT: **Ali Imtiaz**: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Software, Visualization, Writing – original draft, Writing – review & editing; **Chi Yuanying**: Conceptualization, Formal analysis, Project administration, Software, Supervision, Validation, Visualization, Writing – original draft; **Muhammad Farukh Shahzad**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing; **Abdul Raheel**: Formal analysis, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing; **Fahad Sabah**: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing; **Raheem Sarwar**: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft.

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Data availability statement

The data sample includes articles from the Scopus database covering a wide range of publications on the green economy and sustainability from various countries and institutions between 2007 and 2024. The data can be made available upon reasonable request from the corresponding author.

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