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Exploring the Impact of Financial Development on Ecological Footprint: Insights from a Decade of Bibliometric Evidence

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ABSTRACT

This study explores the complex relationship between financial development and ecological footprint, a subject of increasing global importance at the intersection of finance, sustainability, and environmental management. Using the Dimensions database and the bibliometric tool VOSviewer, we analyzed 124 documents published between 2015 and 2024. The analysis identifies key trends, leading contributors, thematic clusters, and collaborative networks, shedding light on how financial systems impact ecological outcomes. Our findings emphasize the growing significance of sustainable finance, including instruments like green bonds and ESG-compliant investments, in addressing the environmental challenges linked to financial development. Regional insights show that China, Pakistan, and Turkey lead research efforts in this field, while growing contributions from Africa and the Middle East underscore the global reach of this topic. Revisiting the Environmental Kuznets Curve hypothesis, the study demonstrates that strong governance and financial innovation are key to accelerating transitions toward sustainable economies. This research makes valuable contributions by offering actionable insights for policymakers, practitioners, and scholars. It underscores the need for tailored financial strategies, interdisciplinary collaboration, and technological advancements to address ecological challenges effectively. By providing a replicable framework, this study lays the groundwork for future research and practical solutions to balance economic growth with environmental conservation.

Keywords: Bibliometric Analysis, Ecological Footprint, Environmental Sustainability, ESG Investments, Financial Development, VOSviewer
JEL Classifications: O16, Q19, Q50

1. INTRODUCTION AND THEORETICAL FRAMEWORK

The connection between economic growth and its effect on the environment has attracted a lot of academic interest. Researchers have been working hard to understand this complex relationship, but there are still gaps in our knowledge, especially in the context of the global financial system and environmental concerns. This study is unique because it utilizes a large database of cited documents, which provides valuable bibliographic information. This study addresses a critical gap by integrating bibliometric insights into the interplay between financial systems and ecological impacts, a nexus often overlooked in existing research. Its novel methodological approach provides a comprehensive overview of a decade's worth of scholarly contributions. By using bibliometric techniques, the researchers were able to analyze documents from 2015 to 2024 after conducting a thorough search. This approach enables a comprehensive exploration of the impact of financial development on the ecological footprint. Through the use of bibliometric tools such as VOSviewer, this study provides strong insights into thematic clusters, influential contributors, and emerging trends, addressing the persistent gaps in the literature. This study distinguishes itself by employing a bibliometric analysis to synthesize insights and uncover thematic clusters, enabling a comprehensive understanding of the interplay between financial systems and ecological footprints. Such an approach bridges existing gaps in the literature, offering novel insights into this dynamic relationship.

There has been a significant amount of research done to examine the connection between the economy and environmental conservation. However, there is still a lack of thorough studies investigating the impact of economic expansion on the environment. Recent advancements in technology, such as AI and blockchain, also offer promising opportunities to improve financial transparency, monitor ecological impact, and promote green investments, potentially changing the role of financial systems in addressing environmental issues. Incorporating AI-driven analytics and blockchain transparency into financial systems not only enhances accountability but also bridges the gap between economic objectives and sustainability imperatives. These innovations represent actionable solutions for mitigating the environmental costs of financial development. By incorporating interdisciplinary perspectives, this research informs policy, strategic planning, and the adoption of sustainable financial practices, emphasizing its practical utility across academic, business, and policy-making domains.

The results of this study offer valuable insights and identify many areas for further exploration in various fields, emphasizing the importance of incorporating ecological considerations into financial policies and decision-making to support long-term environmental sustainability. Using bibliometrics, this research reveals important insights into the complex link between financial development and its environmental impact, systematically gathering crucial perspectives, integrating information, and mapping the intellectual landscape of this evolving area. The results of this study offer important insights and open up many possibilities for further exploration in various fields. This research goes beyond academic curiosity to affect practical uses like creating sustainable policies, crafting business plans, and planning for regional growth. It highlights the importance of collaboration between different disciplines to address the challenges posed by the environmental impact of financial development. Additionally, the study of the relationship between financial development and the ecological footprint creates new opportunities for interdisciplinary teamwork. This research sets a strong foundation for upcoming studies, allowing for the development of innovative approaches and theoretical frameworks. By presenting comprehensive findings, this paper adds to the existing knowledge by deepening our understanding of the complex connections between financial development, sustainability, and environmental effects.

Furthermore, this research prompts critical reflections on the implications of financial decisions and policies on ecological sustainability. It emphasizes the need for conscious consideration of the ecological footprint in financial practices and decision-making processes (Feng et al., 2022; Hasan et al., 2024; Wang et al., 2023). In particular, this study highlights the role of green financial instruments, such as ESG-compliant investments and green bonds, in promoting environmentally sustainable growth. The integration of ecological considerations into economic frameworks and models is essential for achieving long-term environmental sustainability and promoting responsible financial practices (D'Amato and Korhonen, 2021; Goutte and Sanin, 2024; Hariram et al., 2023).

In addition, the results present new opportunities to grasp the complex links between finance, investment strategies, and global sustainability goals. They emphasize the importance of aligning sustainable economic development with environmental constraints, highlighting finance's influential role in promoting environmental conservation. Financial mechanisms have significant implications for maximizing ecological security or for challenging global environmental governance (Aguilera et al., 2021; Cheng et al., 2022; Zhang et al., 2022). The development of finance and, in particular, the diversification of investment options may offer mechanisms to involve potential stakeholders. A broader investment structure would lead to a closer connection between environmental protection, the welfare of societies, and future income (Carrosio and De Vidovich, 2023; Chipalkatti et al., 2021; Safi et al., 2023). In sum, our findings contribute to ongoing debates by identifying key policy implications, such as the importance of tailored financial strategies and green investments, in addressing ecological challenges

Finally, given this theoretical stance, two important questions worth investigating are: The first is to evaluate how the idea and policy regarding a balance between economic development activities and environmental issues are accepted by the current industry from a perspective of financial strategies. The second is to conduct a comprehensive review of the most up-to-date bibliography through the past decade and discern the most critical trends regarding the topic under review to analyze the cumulative dynamics and change in scientific knowledge. Both questions are addressed using a rigorous bibliometric approach, ensuring a systematic and reproducible framework for understanding the intellectual landscape of this emerging field. In using a two-step bibliometric analysis, the empirical results demonstrated both diversity and development in the intellectual bases of research and academia regarding the impacts of "Financial Development" on the "Ecological Footprint." The implications for further research in environmental cooperation, sustainability, ecological security, and financial market liberalization in selected countries are also discussed. Thus, the key academic contribution of this paper lies in using a participative academic literature search and a bibliometric analysis.

2. LITERATURE REVIEW

The relationship between financial development and ecological footprint has been an often-discussed issue, with a great amount of literature on environmental and financial studies. The existing research can be divided into two branches. Firstly, from the theoretical perspective, the link between financial development and environmental quality can be effectively explored (Fakher et al., 2021; 2022; Gao et al., 2022; Ozturk et al., 2024). Secondly, many studies focus on the specific topic of the effect of financial development on the ecological footprint (Acar et al., 2023; Shahbaz et al., 2023). Although there is a wealth of literature on this subject, the relationship between these aspects continues to be disjointed, frequently tackling either financial mechanisms or environmental results in isolation. The fragmented nature of existing research underscores the need for a cohesive framework that examines financial mechanisms and environmental outcomes concurrently.

This study contributes by mapping the intellectual landscape and identifying integrative approaches. Additionally, recent progress in financial systems, particularly concerning green finance and digital financial platforms, is still insufficiently examined regarding its ecological effects. However, the relationship between financial development and ecological footprint in recent years may not have been extensively studied. Thus, in this section, this study involves explaining the relationship between financial development and the ecological environment and summarizing the literature on the influence of financial development on the ecological environment.

2.1. Theoretical Foundations

Numerous mechanisms for the linkage between financial development and environmental factors have been provided in the literature. The link between financial development and environmental quality can be further explained through several reasons, including improved access to cash for individuals and enterprises to make investments in clean production and investment in new technology for promoting energy efficiency and lower emission (Anser et al., 2020; Ponce et al., 2021; Zhang et al., 2022). Empirical findings suggest that green financial products, such as ESG-compliant investments, can act as significant mediators in channeling resources toward environmentally sustainable projects. This indicates a vital role for tailored financial tools in mitigating ecological degradation. These factors can lead to a decrease in harmful public health effects and provide more income for most individuals. Therefore, there is a general consensus among these researchers that weaker regulations and improper financial development will generally result in more sulfur dioxide being released (Canh et al., 2021; Li et al., 2021; Qin et al., 2021; Xu et al., 2023). Similarly, the availability of green financial products, such as green bonds, is increasingly recognized as a mechanism to channel resources toward environmentally sustainable projects, reducing environmental degradation.

In addition, several pieces of literature reinforce this conclusion by addressing that these market-based mechanisms provide strong financial opportunities to firms (Liao et al., 2023; Shen et al., 2023). Hence, the efficient use of environmental control strategies results in substantially lower SO2 levels. From the motivation theory perspective, communication from the company's management is crucial in creating a common ground with the employees and providing an incentive framework for the employees to yield sustainability initiatives (Chygryn et al., 2020; Kong et al., 2021).

Theoretical foundations allow us to incorporate the financial system into pollution-centric theoretical constructs, explaining the interaction between economic growth and the environment (Wang et al., 2024; Yang and Walker, 2024). Adhering to these frameworks, financial systems should channel resources into environmentally sustainable investments. Less consensus, however, exists regarding where financial systems do not abandon ecological sustainability, acknowledging the role of credit allocation and evaluation of potential investment risks (Oman et al., 2024; Van Niekerk, 2024). Empirical implications of these theories are well recognized as part of the basis for investment decisions, including ecological footprints. In the empirical sphere, for example, it is postulated that financial development slows down ecological damage, investigating the durability of these surveys, expanding the original scope of industry research, or focusing on the most environmentally damaging industries such as mining or the transportation sector (Abid et al., 2022; Ahmad et al., 2023; Yang and Ni, 2022). The financial system can incentivize or deter ecological sustainability based on investment allocations. However, gaps remain in understanding the mediating factors, such as governance quality, technological innovation, and cross-sectoral cooperation, which can modulate this relationship.

A dominant, theoretically driven refutational position postulates the positive modernization of environmental performance and the tendency of cleaner post-industrial economies (Blakeley and Evans, 2023; Rudenko et al., 2022). This position is associated with neo-classical endogenous growth models that permit investigating the financial impact on environmental footprints. A key aspect is that cleaner economies, even in the context of higher economic growth, should protect the environment more (Magazzino et al., 2022). As a result, the interaction between finance and ecological footprints could be both direct and/or moderated or mediated through other conducive economic growth determinants. Therefore, a priori theoretical discernment, especially from endogenous growth theory categories, is essential for the modern contribution of this study.

The following subsection discusses in further detail the importance of the studied constructs, providing rationale for the need to explore each construct from subfields of economics. These discussions include finance and growth literature while having a critically informed bearing that permits us to inquire further on: (i) the functioning of the finance-ecological system; (ii) the financial determinants of sustainable/ecological footprint growth. The examination of theoretical frameworks such as the Environmental Kuznets Curve (EKC) offers profound insights into the manner in which financial advancement may initially exacerbate ecological repercussions, yet ultimately mitigate them through technology-fueled remedies. This necessitates an extensive review of Kuznets-oriented economic theories pertinent to the prevailing empirical focus, encompassing an analysis of disputes or inconsistencies arising from these theoretical constructs. A specific discussion on the financial system's functional deciders is vital given the complex nature of finance-energy savings-investment links. The section closes with an overview and delineation of economics-related theories within the finance-sustainable growth domain that are relevant to the explored finance-ecological footprint system.

2.2. Previous Studies on the Relationship between Financial Development and Ecological Footprint

The research on the relationship between financial development and ecological footprint has made some progress in the past. Quantitative analyses remain the main studies in the existing literature (Bauer et al., 2021; Linnenluecke et al., 2020). Case studies also account for a large proportion, which reveals the relevance of financial development to ecological sustainability from an individual or local perspective (Abbasi et al., 2022; Jahanger et al., 2022; Saud et al., 2020; Yang et al., 2021).

While preceding investigations, such as those conducted by Baloch et al. (2019) and Zahoor et al. (2022), offer invaluable perspectives regarding the influence of financial development on the aggravation or alleviation of environmental repercussions, they predominantly depend on econometric models, thereby neglecting bibliometric analyses of this relationship. Our research endeavors to bridge this gap, delineating the intellectual terrain of studies pertaining to financial development and ecological footprints in order to reveal critical thematic and regional patterns.

Theoretical papers are few, exploring the mechanisms of how financial development affects the ecological footprint. Moreover, the empirical studies show a lack of common ground in consistent results (Bozionelos and Simmering, 2022; Enfield, 2020; Gardner et al., 2021). At present, the research methods of finance and sustainable development mainly include theoretical deduction and quantitative analysis. Nevertheless, the empirical findings may not be uniformly consistent due to variations in methodologies and the selection of variables, thereby complicating the assessment of the strength of the relationship between financial development and environmental issues. Moreover, the interaction of external factors, including globalization, trade liberalization, and regulatory frameworks, further complicates this relationship, thereby necessitating a greater number of integrative studies.

The development trend of financial development and ecological footprint studies shows that more and more scholars pay attention to the impact of regional financial development on ecological footprint (Balsalobre-Lorente et al., 2023; Ozturk et al., 2024). However, the ecological footprint issues of the main producing areas around the world have not attracted adequate attention. Our investigation reveals a lack of literature addressing the correlation between financial development and ecological footprint, particularly in relation to high-quality data derived from large-scale manufacturing. Subsequent investigations ought to address these deficiencies, with particular emphasis on the integration of cutting-edge technologies such as artificial intelligence and blockchain within financial decision-making processes, along with their ecological ramifications.

3. METHODOLOGY

This scholarly investigation employs a bibliometric analysis to examine the intriguing convergence of financial development and ecological footprint research, a domain that has recently garnered significant attention. Bibliometric analysis provides a comprehensive and quantitative framework for evaluating the progression, patterns, and trends of scientific publications, which is of considerable importance. The study aspires to close the research gap by bringing together existing knowledge and recognizing key themes, contributors, and trends in how financial development influences ecological footprint. This method not only showcases the historical advancements in the field but also reveals emerging research opportunities and promising directions for future exploration.

The Dimensions database was selected for its extensive coverage of multidisciplinary research, especially in promising areas like financial development and sustainability. In comparison to other databases, such as Scopus or Web of Science, Dimensions provides enhanced access to open-access articles and includes a wider variety of interdisciplinary journals, which is incredibly beneficial for uncovering intricate connections in your area of interest. VOSviewer was employed for bibliometric visualization because of its strength in analyzing large datasets, facilitating the identification of thematic clusters, collaboration networks, and citation patterns that might otherwise go unnoticed. The utilization of VOSviewer enabled the identification of co-authorship patterns, thematic clusters, and citation networks, providing granular insights into intellectual trajectories within the field. Its ability to analyze co-authorship, co-citation, and keyword co-occurrence data further enhanced the depth of the analysis. This methodological approach ensured a rigorous and replicable analysis of the intellectual structure and thematic trends in the research field.

The data collection process began with a systematic search using the keywords "Impact of financial development" AND "ecological footprint." The search was limited to abstracts and titles, focusing exclusively on peer-reviewed articles and book chapters. An initial dataset of 263 publications was retrieved. To enhance the relevance and focus of the study, additional filters were applied, restricting the timeframe to publications from 2015 to 2024 and the field to environmental sciences, which reduced the dataset to 127 documents. To ensure relevance, documents were filtered based on inclusion in peer-reviewed journals, alignment with environmental science domains, and publication within the 2015-2024 period. This rigorous refinement resulted in a final dataset of 124 documents specifically classified under the subfield of "Environmental Management". This selective approach ensures that the data are representative of the intersection between financial development and ecological footprint, focusing on studies most pertinent to the research questions. These documents form the basis for the bibliometric analysis, which examines key indicators such as publication trends, citation networks, keyword co-occurrence, and collaborative patterns among authors and institutions.

The bibliometric analysis was carried out using a systematic and structured approach, which encompassed the stages of data collection, verification, and subsequent evaluation. A variety of analytical tools were utilized to illustrate and visually represent the connections among authors, countries, and keywords. Specifically, co-citation analysis was utilized to pinpoint influential works, bibliographic coupling was applied to explore common intellectual frameworks, and keyword co-occurrence was used to clarify thematic priorities and emerging trends within the discipline. This systematic approach guarantees the integrity and replicability of the results while addressing potential biases inherent in bibliometric data, such as ling istic and database constraints. By amalgamating quantitative metrics with qualitative assessments, this investigation provides a thorough overview of the research landscape and proffers actionable insights for forthcoming inquiries.

4. RESULTS

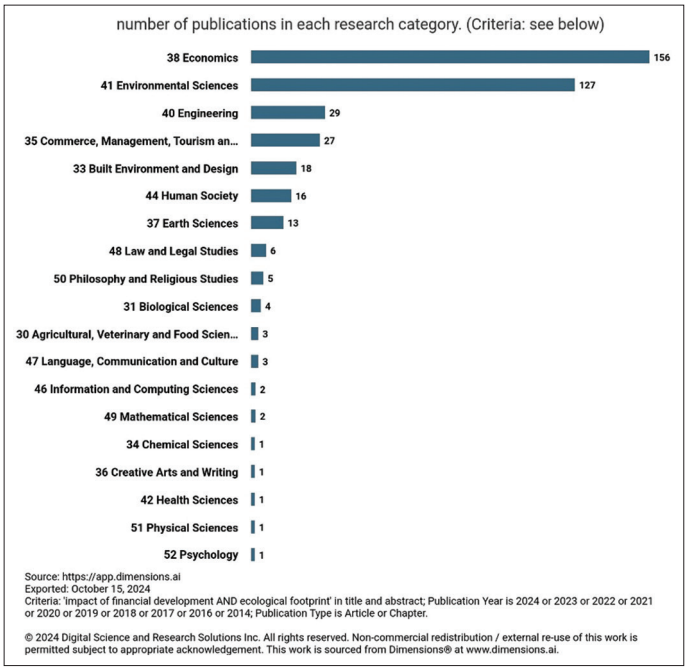
4.1. Bibliometric Overview

4.1.1. Research categories and subfields

To analyze the distribution of research on the impact of financial development (FD) on the ecological footprint (EF), 263 publications were retrieved using the Dimensions database. These were categorized into research fields. "Economics" (38) led with 156 publications, followed by "Environmental Sciences" (41), which accounted for 127 publications. This categorization underscores the interdisciplinary nature of this field (Figure 1).

To refine the dataset, we applied a filtering threshold to limit the focus to subfields within "Environmental Sciences (Figure 2)." By narrowing the focus to the "Environmental Management" subfield, this analysis ensures that the findings directly contribute to actionable insights within the financial development and sustainability nexus. This step ensured that the analysis remained relevant to the environmental and sustainability aspects of FD.

Figure 1: Number of publications on the impact of FD on EF per research category



4.1.2. Temporal trends in publications

The temporal trends in publication output were analyzed over the period from 2015 to 2024, revealing a growing interest in the field. The dataset shows a steady increase in publications since 2019, with a peak in 2024 (36 publications as of mid-October). This rise reflects the growing recognition of the importance of FD in addressing environmental challenges (Figure 3).

This subsection highlights the scope of the research and its increasing relevance over time. The filtering of subfields ensures a focused dataset, while the temporal analysis demonstrates a surge in scholarly interest, particularly in recent years.

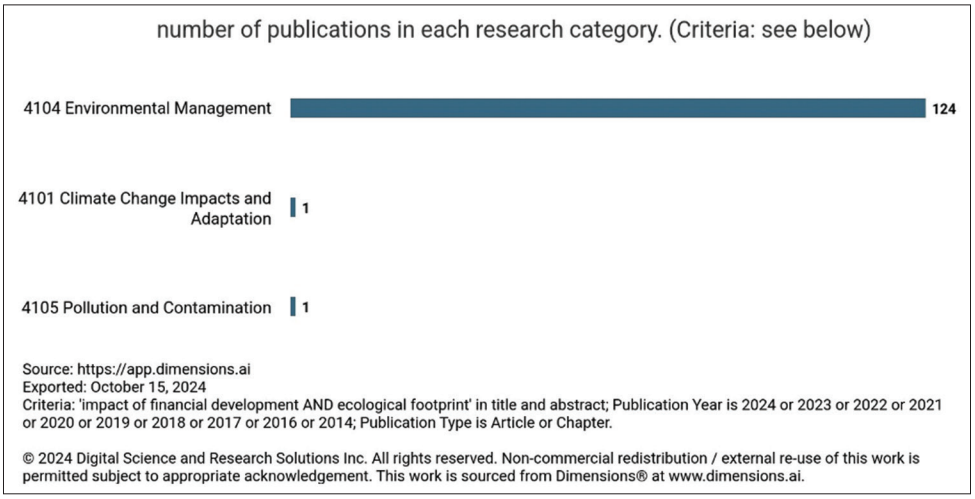
4.2. Themes and Keywords

4.2.1. Co-citation analysis of authors

A co-citation analysis was performed with a threshold of 200 citations per author, identifying 17 highly influential authors. This analysis highlights thematic convergence, with key authors emphasizing energy transitions, sustainable finance, and the globalization-environment interface. The thematic clusters reveal a multidisciplinary approach bridging economics, policy, and environmental studies. The network visualization (Figure 4) associated with a qualitative analysis of authors' contributions, revealed three thematic clusters:

a. Energy transitions and policy implications: Shahbaz (586 citations) and Ilhan Ozturk (477 citations) were prominent contributors, focusing on FD's role in renewable energy adoption and policy interventions.
b. Renewable energy, financial innovation, and governance: Zahoor Ahmed (429 citations) and Tomiwa Sunday Adebayo (426 citations) led this cluster, emphasizing sustainable finance and green governance mechanisms.
c. Globalization, trade, and environmental impacts: This theme, led by Ahmad and others, explored the environmental repercussions of globalization and trade practices.

Figure 2: Subfields within environmental sciences



4.2.2. Keyword co-occurrence

The keyword co-occurrence analysis applied a threshold of 13 occurrences per keyword, identifying 26 frequently used terms from a total of 3,276. These terms were grouped into three clusters, as shown in Figure 5:

- Red cluster: Keywords such as "sustainability," "globalization," and "technological innovation" highlighted macroeconomic and systemic perspectives.
- Green cluster: Terms like "GDP," "economic development," and "ARDL models" emphasized econometric and quantitative methods.
- Blue cluster: Keywords including "Environmental Kuznets Curve" (EKC) and "policymakers" pointed to theoretical frameworks and policy-driven research.

4.2.3. Linking themes and keywords

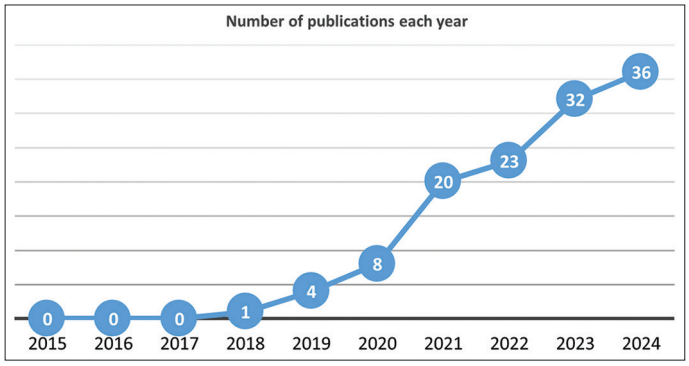
A comparative analysis revealed strong alignment between the themes identified in co-citation analysis and the keyword clusters:

- The red cluster keywords align with the Energy Transitions and Policy Implications theme.
- The green cluster keywords correspond to the Renewable Energy, Financial Innovation, and Governance theme.
- The blue cluster keywords relate to the Globalization, Trade, and Environmental Impacts theme.

This alignment reinforces the robustness of the thematic analysis and highlights the interdisciplinary nature of the research.

This subsection integrates co-citation and keyword analyses to reveal recurring themes in the field. The identified themes and their alignment with keywords provide a coherent framework for understanding the focus areas of FD-EF research.

Figure 3: Publications each year on FD and EF



4.3. Contributions and Collaborations

4.3.1. Author contributions

An analysis of authorship patterns revealed contributions from 762 researchers. A threshold of at least four publications per author identified 16 prolific contributors. Adebayo, Tomiwa Sunday led with 12 documents and 865 citations, followed by Zahoor Ahmed and Muhammad Usman. Notably, Songsheng Chen, with only four documents, achieved the highest citation count (910), indicating significant impact (Table 1).

4.3.2. Institutional contributions

The institutional analysis applied a threshold of at least six publications per institution and identified 501 organizations. The Beijing Institute of Technology (China) led with 11 documents and 2,005 citations. Pakistani institutions, such as Government College University, Faisalabad (975 citations), also featured prominently, reflecting regional contributions to the field (Table 2).

4.3.3. Co-authorship networks

The co-authorship network analysis applied a threshold of two documents per author and 200 citations, revealing three primary collaboration clusters (Figure 6). These clusters reflect the diversity of research themes and the collaborative nature of FD-EF studies.

Figure 4: Authors' co-citation network

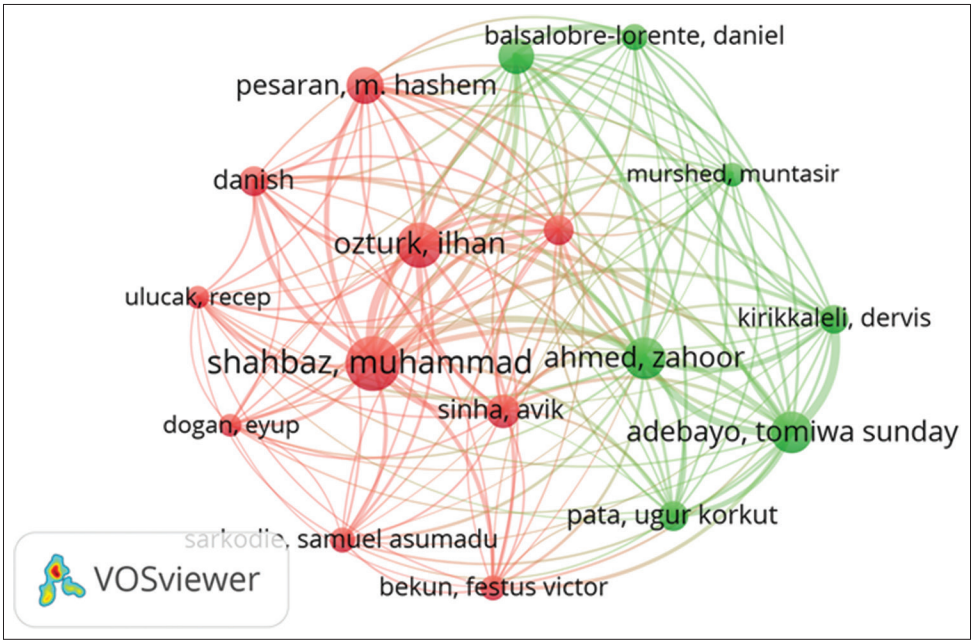


Figure 5: Visualization of keyword co-occurrence network

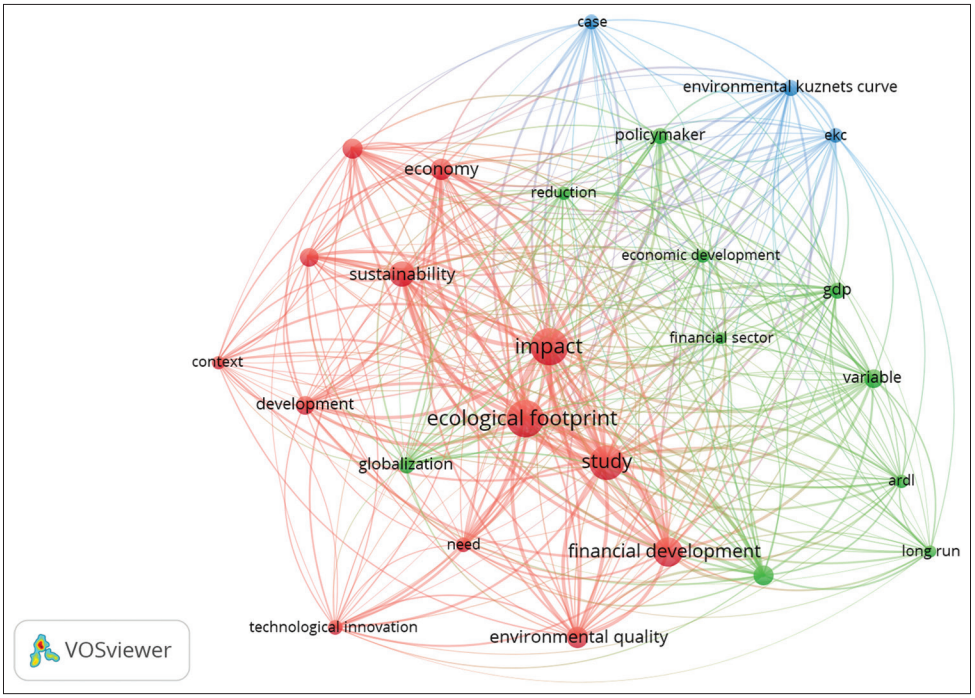


Table 1: Most documented authors in the impact of FD on EF

Rank	Authors	Documents	Citations
1	Adebayo, Tomiwa Sunday	12	865
2	Ahmed, Zahoor	9	773
3	Usman, Muhammad	8	892
4	Dada, James Temitope	7	184
5	Pata, Ugur Korkut	7	256
6	Ahmad, Mahmood	6	445
7	Kirikkaleli, Dervis	6	564
8	Ahmad, Munir	5	430
9	Mehmood, Usman	5	160
10	Sharif, Arshian	5	290
11	Arnaut, Marina	4	96
12	Chen, Songsheng	4	910
13	Godil, Danish Iqbal	4	363
14	Naqvi, Syed Asif Ali	4	133
15	Shah, Syed Ale Raza	4	83
16	Ullah, Sami	4	198

This subsection emphasizes the diversity of contributions, with significant input from authors, institutions, and collaborative networks. The findings highlight the global and interdisciplinary nature of the field.

4.4. Citation and Source Analysis

4.4.1. Most cited documents

An analysis of citation patterns identified the most influential studies, with a threshold of 100 citations per document. Key contributions include Baloch et al. (2019), with 434 citations, and Kihombo et al. (2021), with 277 citations. These studies provide foundational insights into the interplay between FD and EF across various contexts (Table 3).

4.4.2. Co-citation of sources

A co-citation analysis of journals applied a threshold of at least 50 citations per source, identifying 27 influential journals (Figure 7). Environmental Science and Pollution Research emerged as the most central journal, with 53 documents and 4,052 citations.

This subsection highlights the key sources and documents that shape the field, emphasizing the centrality of certain journals and studies in advancing FD-EF research.

5. DISCUSSION

This research serves as a significant contribution to the expanding dialogue about the intricate connection between financial growth and ecological sustainability. One of the most significant contributions of this study lies in its nuanced exploration of how financial development influences ecological outcomes, bridging existing gaps in the literature. A pivotal revelation from our investigation is the complex interplay between financial structures and environmental repercussions, calling into question some earlier beliefs while affirming others. For example, Zahoor et al. (2022) and Kihombo et al. (2021) have convincingly demonstrated the dual purpose of financial development: Boosting economic growth while potentially increasing environmental damage. Our findings complement these studies by highlighting the extent to which the magnitude of environmental impacts is influenced by regional contexts, governance quality, and the degree of policy implementation targeting sustainability. These findings advocate for region-specific policies that integrate financial innovations with environmental goals. For instance, green financial mechanisms could drive localized transitions toward sustainable practices, particularly in resource-intensive economies. This crucial distinction underscores the potential ineffectiveness of a "one-size-fits-al" approach and emphasizes the importance of tailored financial and environmental measures.

Another important observation concerns the potential for mitigation as identified through progress in technology and

Table 2: Main document-publishing organizations in the impact of FD on EF

Rank	Organization	Documents	Citations
1	Beijing Institute Of Technology (China)	11	2005
2	Lebanese American University (Lebanon)	11	186
3	Cyprus International University (Cyprus)	9	840
4	Government College University, Faisalabad (Pakistan)	9	975
5	Ilma University (Pakistan)	9	545
6	Azerbaijan State University Of Economics (Azerbaijan)	7	69
7	Obafemi Awolowo University (Nigeria)	7	184
8	Xi'an Jiaotong University (China)	7	322
9	University Of Johannesburg (South Africa)	6	299
10	University Of Management And Technology (Pakistan)	6	167
11	University Of The Punjab (Pakistan)	6	222
12	Wuhan University (China)	6	209

Figure 6: Co-authorship visualization network (authors)

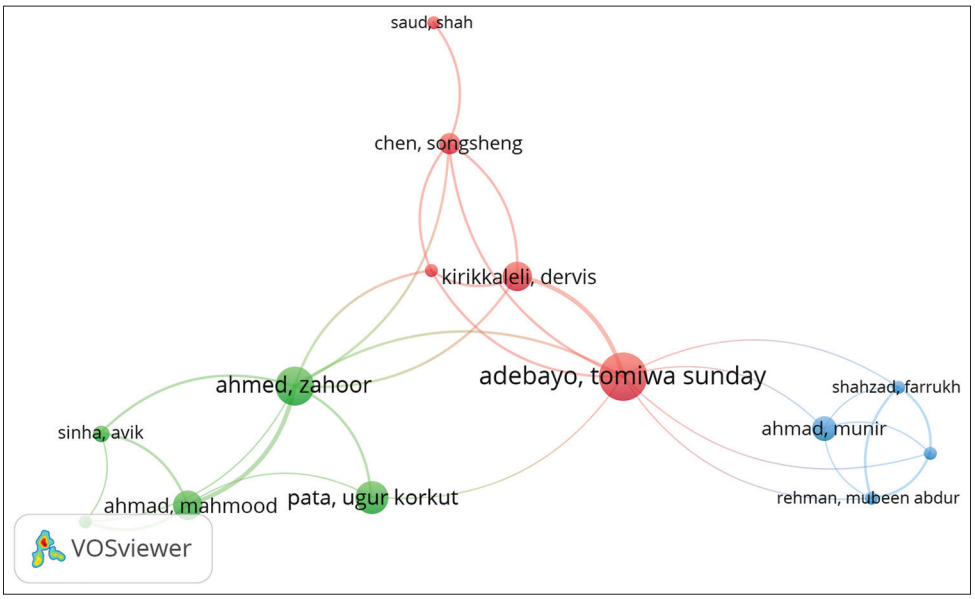


Figure 7: Co-citation visualization of journals

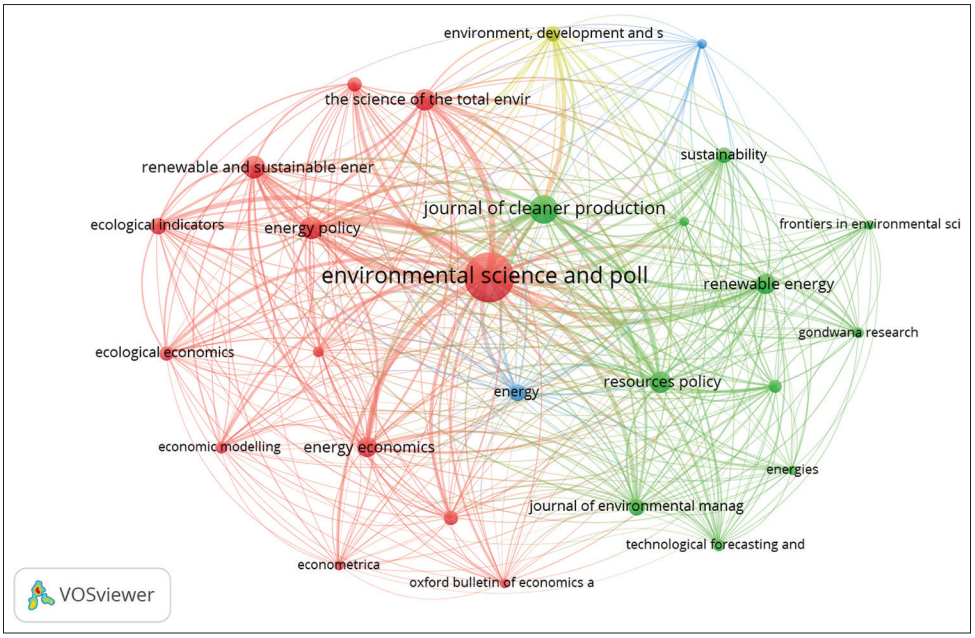


Table 3: Most cited documents on the impact of FD on EF

Rank	Year	Authors	Document Name	Source	Citations	Region/scope	Main findings	Methodology
1	2019	Baloch et al.	The effect of financial development on ecological footprint in BRI countries: evidence from panel data estimation	Environmental science and pollution research	434	BRI Countries	Financial development increases the ecological footprint. Emphasizes a need for policies balancing growth and environmental concerns.	Driscoll-Kraay Panel data estimation
2	2021a	Kihombo et al.	Linking financial development, economic growth, and ecological footprint: what is the role of technological innovation?	Environmental science and pollution research	277	West Asia and Middle East nations	Technological innovation mediates the financial development-ecological footprint relationship, offering a pathway to sustainable development.	Panel econometric analysis
3	2021a	Yang et al.	Remittance inflows affect the ecological footprint in BICS countries: do technological innovation and financial development matter?	Environmental science and pollution research	202	BICS Countries	Financial development and technological innovation significantly influence the ecological footprint in remittance-dependent economies.	Panel data estimation
4	2021	Zahoor et al.	Clean energy investment and financial development as determinants of environment and sustainable economic growth: evidence from China	Environmental Science and Pollution Research	194	China	Clean energy investments combined with financial development foster sustainable growth and reduce ecological footprints.	Case study analysis
5	2021	Zeraibi et al.	The influences of renewable electricity generation, technological innovation, financial development, and economic growth on ecological footprints in ASEAN-5 countries	Environmental Science and Pollution Research	155	ASEAN-5 Countries	Renewable energy and technological innovation positively influence sustainability while financial development decreases it in the ASEAN-5 region.	Panel econometric modeling
6	2020	Aydin and Turan	The influence of financial openness, trade openness, and energy intensity on ecological footprint: revisiting the environmental Kuznets curve hypothesis for BRICS countries	Environmental science and pollution research	143	BRICS Countries	The environmental Kuznets curve hypothesis is not confirmed for all BRICS. The role of trade openness in ecological impacts is validated in India, and both India and South Africa for trade openness.	EKC hypothesis analysis
7	2021	Ibrahim and Vo	Exploring the relationships among innovation, financial sector development and environmental pollution in selected industrialized countries	Journal of environmental management	142	Industrialized Countries	Innovation and financial development jointly influence environmental pollution, emphasizing the role of institutional policies.	Mixed-methods econometrics
8	2022	Xu et al.	Load Capacity Factor and Financial Globalization in Brazil: The Role of Renewable Energy and Urbanization	Frontiers in environmental science	137	Brazil	Highlights renewable energy and urbanization as key factors in mitigating the ecological impact of financial globalization.	Case study, panel analysis
9	2021	Kihombo et al.	Is there a tradeoff between financial globalization, economic growth, and environmental sustainability? An advanced panel analysis	Environmental science and pollution research	133	Global	Advanced panel analysis reveals trade-offs between financial globalization and environmental sustainability.	Advanced panel analysis

(*Contd...*)

Table 3: (*Continued*)

Rank	Year	Authors	Document Name	Source	Citations	Region/scope	Main findings	Methodology
10	2021	Zia et al.	Striving towards environmental sustainability: how natural resources, human capital, financial development, and economic growth interact with ecological footprint in China	Environmental science and pollution research	121	China	Interactions among natural resources, financial development, and human capital are crucial for mitigating China's ecological footprint.	Structural econometric model
11	2019	Rahman et al.	Nexus between financial development, energy consumption, income level, and ecological footprint in CEE countries: do human capital and biocapacity matter?	Environmental science and pollution research	118	CEE Countries	Financial development and energy consumption exacerbate ecological footprints, but human capital can mitigate these effects in CEE countries.	Panel data estimation
12	2020	Doytch	The impact of foreign direct investment on the ecological footprints of nations	Environmental and Sustainability Indicators	110	Global	FDI contributes to ecological footprints, particularly in resource-dependent economies, underscoring the need for sustainable investment policies.	Panel econometric modeling
13	2019	Fakher	Investigating the determinant factors of environmental quality (based on ecological carbon footprint index)	Environmental science and pollution research	104	Global	Identifies key factors influencing ecological carbon footprints, emphasizing renewable energy and sustainable practices.	Statistical analysis

the encouragement of green financing. Prior studies, including those conducted by Yang et al. (2021) and, emphasize economic objectives at the expense of ecological sustainability, yet this investigation clarifies methods to harmonize that inconsistency. For example, allocations toward renewable energy and infrastructure initiatives may harmonize economic and environmental imperatives, a conclusion that resonates with Doytch (2020)'s advocacy for sustainable financial globalization. In this regard, our study uniquely highlights the role of financial innovation, such as green bonds and sustainability-linked loans, as instruments to align economic growth with environmental objectives. This finding enriches the discourse by connecting technological innovation with financial mechanisms to address environmental challenges.

Notably, the function of financial development in influencing ecological outcomes emerges as a focal point in this study, distinguishing itself from Xu et al. (2022)'s accentuation on urbanization and energy consumption. Although urbanization continues to be a critical driver, our findings indicate that purposefully designed financial instruments, such as green bonds and investments adhering to Environmental, Social, and Governance (ESG) criteria, could enhance the adoption of renewable energy and promote a transition toward more sustainable economies. These findings further substantiate Ahmad et al. (2021)'s assertion regarding the necessity of robust financial frameworks to foster green technological advancements. Moreover, our research demonstrates that regions with access to international financial markets and strong institutional frameworks tend to exhibit faster transitions toward eco-friendly practices, adding a new dimension to the existing body of knowledge.

Emerging technological advancements, including artificial intelligence (AI) and blockchain technology, are positioned to fundamentally transform the manner in which financial systems influence ecological footprints. AI possesses the capability to enhance investment strategies by pinpointing high-impact environmentally sustainable projects while concurrently reducing operational inefficiencies, whereas blockchain technology facilitates transparency in sustainable financial practices, thereby addressing enduring challenges related to accountability. Our findings suggest that these technologies could serve as critical enablers of green finance, especially in regions with fragmented financial markets. Moreover, integrating AI-driven predictive models with ESG frameworks could help stakeholders identify areas where financial development can yield the most significant environmental benefits. These innovations, along with the ascendance of Environmental, Social, and Governance (ESG) principles, furnish a framework for both policymakers and practitioners to further sustainability objectives.

Our findings also correspond with the EKC hypothesis, as evidenced by the research conducted by Alshehry and Belloumi (2015) and Altouma et al. (2024). This theoretical model asserts that the early stages of financial development cause a surge in ecological degradation; however, in the long term, investments targeting innovation and sustainability are likely to alleviate

this trend. Yet, our study expands the standard EKC narrative by emphasizing the essential role of governance quality and the financial sector's innovation capacity in driving this development trajectory. Zones marked by solid governance frameworks and available green financing are poised for a more rapid reversal of ecological damage. This adds a new perspective to the EKC discourse, highlighting that regions with robust financial ecosystems and innovative technologies can achieve environmental improvements faster and more effectively.

In dealing with these findings, it seems absolutely crucial that interdisciplinary collaboration is somehow made a priority. Environmental scientists, economists, and technology experts must collaborate to design integrated frameworks that address sustainability challenges holistically. This interdisciplinary collaboration is essential to bridge gaps in data, methodologies, and practical applications, fostering actionable solutions that align financial incentives with environmental preservation. For example, the amalgamation of artificial intelligence with ecological data may act as a crucial component in developing adaptive strategies that seek to enhance resource efficiency, whereas blockchain technology could potentially transform carbon credit markets by offering enhanced traceability. The creation of such integrated models could serve as the foundation for actionable policy frameworks that reconcile financial and environmental objectives.

The consideration of these advancements by policymakers could be beneficial, especially as they aim to reinforce regulatory frameworks intended to advance sustainable finance. For professionals, the introduction of AI-based and blockchain-enabled systems could potentially lessen operational risks, bolster credibility, and ensure compliance with global sustainability standards. Such initiatives could not only ease environmental impacts but could also, if organizations play their cards right, position them as champions of responsible financial stewardship. This dual benefit aligns financial growth with corporate social responsibility, enhancing both profitability and environmental outcomes.

This extensive research underscores the urgent need for systemic modifications to harmonize economic development with environmental conservation by incorporating these enlightening results into the vital context of financial advancement and sustainability. The study accentuates the significance of synchronizing economic progress with ecological preservation. Future investigations may need to delve deeper into the interactions among state-of-the-art technologies, regulatory structures, and fiscal strategies to potentially reveal groundbreaking approaches for attaining the complex equilibrium between environmental and economic aims. Moreover, longitudinal studies and cross-regional analyses could provide deeper insights into how financial systems adapt to changing environmental policies and technological advancements.

6. CONCLUSION

This research presents a fresh and comprehensive bibliometric examination of the connection between financial development and ecological footprint, tackling a vital and dynamic field of study that lies at the crossroads of finance, sustainability, and environmental management. By evaluating publication trends, mapping thematic clusters, and identifying key contributors, this study highlights the critical role of financial systems in promoting ecological sustainability. It underscores the importance of aligning financial instruments, policy frameworks, and technological innovations with environmental objectives, emphasizing that achieving sustainable development requires joint efforts from all stakeholders. Future studies should explore more deeply the interactions between emerging technologies and financial systems to identify transformative solutions that mitigate ecological effects. This interdisciplinary approach would bridge existing gaps and offer practical insights for scholars, policymakers, and practitioners alike.

Remarkably, the study emphasizes the significant roles played by China, Pakistan, and Turkey, while also revealing rising contributions from Africa and the Middle East, highlighting the international aspect of the discussion. The comparative analysis of regional contributions not only demonstrates growing global interest but also underscores disparities in research focus and resource allocation that must be addressed for equitable advancements. These findings underscore a growing awareness of the dual imperatives of economic growth and environmental sustainability in these regions, indicating a movement towards enhanced global collaboration.

The research presents several innovative contributions to the existing literature. This study introduces a replicable bibliometric methodology and identifies critical gaps in regional and sectoral research, emphasizing the urgent need for inclusivity in sustainable finance discussions. First, it highlights the thematic convergence of financial development with renewable energy transitions, green finance, and sustainable globalization, reflecting the interdisciplinary richness of this research area. Second, it identifies critical gaps, particularly in socio-economic contexts of underrepresented regions, and calls for approaches that are more inclusive to addressing sustainability challenges. This observation emphasizes the importance of tailored strategies to address distinct regional challenges and opportunities in achieving sustainable finance. Third, it highlights the growing use of bibliometric approaches in exploring the interactions between financial systems and environmental impacts, offering a replicable model for subsequent research. Such methodologies facilitate monitoring the progression of research themes, enabling early identification of emerging areas of interest.

The results hold considerable significance for scholars, industry professionals, and policymakers. For scholars, this research lays the groundwork for additional exploration of less-examined areas, such as the integration of financial growth with climate adaptation measures and innovations in sustainable technology. Practitioners may utilize these findings to formulate pioneering financial instruments, including green bonds and sustainable investment portfolios, which are aligned with global climate objectives. For policymakers, the findings advocate the formulation of robust regulatory frameworks, fiscal incentives,

and international collaborations to promote sustainable financial practices and address ecological challenges effectively. By doing so, stakeholders can cultivate a synergistic approach to economic expansion and environmental preservation, facilitating sustainable development across diverse contexts.

The future trends in this research area are incredibly encouraging. Longitudinal analyses and case studies could complement these trends, offering deeper insights into causal mechanisms and the scalability of financial innovations across diverse economic contexts. The growing incorporation of cutting-edge technologies, including artificial intelligence and blockchain, in financial systems opens up exciting opportunities to enhance transparency, accountability, and efficiency in green finance. For example, AI-driven tools can optimize resource allocation and predict environmental impacts, while blockchain technologies can effectively verify and track green investments, ensuring adherence to sustainability goals. Correspondingly, the growing recognition of the critical role of institutional structures and regional alliances in fulfilling sustainability aims points to a promising area for additional scrutiny. Moreover, the persistent evolution of Environmental, Social, and Governance (ESG) standards and their assimilation into financial decision-making presents substantial opportunities to redefine sustainable finance practices globally. Longitudinal and case-study-based analyses could complement these developments, providing context-specific insights to improve the design of policies and financial instruments.

This study acknowledges some limitations despite its contributions. By relying solely on the Dimensions database, potential significant works from other indexed sources may have been excluded. Future research could address this limitation by incorporating multiple bibliometric databases, such as Scopus and Web of Science, to provide a more comprehensive view. The primary focus on the 2015-2024 period may overlook earlier foundational studies that could provide additional context to the trends observed. Furthermore, the study prioritizes descriptive observations over causal relationships, which could be explored further in future research using econometric or experimental methods. Greater attention to the unique challenges and opportunities faced by different regions, sectors, or industries is also needed to develop actionable insights tailored to specific contexts. Exploring financial practices within industry-specific frameworks could offer nuanced solutions to pressing ecological concerns.

At its core, this research significantly enhances our understanding of the intricate interplay between economic progress and environmental conservation. Furthermore, it lays the groundwork for forthcoming interdisciplinary investigations and pioneering policy initiatives. By synthesizing its findings with emerging technologies and actionable policy recommendations, the study provides a framework for balancing economic growth and ecological preservation in an era of rapid environmental and economic change. Recognizing its limitations and building upon its findings, this field of study has the potential to provide transformative insights for meeting global sustainability objectives amidst rapid economic and environmental shifts. Meeting these objectives will necessitate ongoing collaboration, innovation, and evidence-based policymaking to ensure that financial systems become enablers of sustainable development rather than contributors to environmental harm.

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