ESG Integration and Green Computing: A 20-Year Bibliometric Analysis

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Article

ESG Integration and Green Computing: A 20-Year Bibliometric Analysis

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Abstract: As businesses increasingly prioritize sustainability, integrating Environmental, Social, and Governance (ESG) principles with green computing has emerged as a critical strategy. However, research remains fragmented regarding how these two domains interact within the Triple Bottom Line (TBL) framework. This study conducts a bibliometric analysis of 750 articles published between 2004 and 2024, using multiple correspondence and co-citation analyses to identify key trends. The findings highlight a strong correlation between green computing practices and improved economic outcomes. Results indicate that China and the United States lead research output in this field, with a significant rise in publications post-2018, driven by regulatory pressures and corporate sustainable initiatives. Our findings emphasize that companies integrating green computing with ESG strategies can achieve long term financial sustainability while meeting Environmental and social responsibilities. The study provides insights from business leaders, policymakers, and researchers by identifying critical gaps and future research direction, including industry – specific applications and policy frameworks to accelerate ESG adoption in technology – driven enterprises. Future research should address practical challenges in implementing these practices across different industries and explore the long-term impacts of ESG integration on business performance.

Keywords: ESG; sustainability; green computing; triple bottom line; bibliometric analysis; vosviewer; corporate sustainability

1. Introduction

The intersection of digital technology, information systems, and green computing has created a dynamic environment for contemporary businesses. As the organizations increasingly prioritize sustainability, integrating ESG criteria has emerged as a focal point. This shift is particularly significant with the advent of the TBL business model, which incorporates economic considerations alongside social and environmental aspects [1]. Simultaneously, green computing a field focusing on reducing the environmental footprint on Information Technology (IT) has emerged a critical tool for achieving sustainable corporate practices [2]. The convergence of ESG and green computing presents an opportunity to optimize resource efficiency, enhance corporate governance, and promote social responsibility while maintaining economic growth [3].

The TBL framework introduced by Elkington [4], provides a comprehensive approach to evaluating corporate success by considering economic, environmental, and social dimensions. Traditional business models prioritize financial performance, but the rising urgency of climate change, energy consumption, and regulatory compliance has necessitated a broader focus on sustainability [5]. Within this framework, green computing plays a pivotal role by reducing energy consumption, minimizing e-waste, and enhancing IT system efficiency [6]. Additionally, advanced digital technologies such as cloud computing, blockchain, and artificial intelligence are being

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leveraged to improve ESG reporting, track carbon emissions, and develop energy-efficient computing infrastructures [7].

Despite the growing interest in ESG and green computing, research remains fragmented, with studies often addressing these areas separately. While existing literature explores the economic benefits of ESG adoption [8] and the environmental impact of IT systems [9], there is limited analysis of how green computing aligns with the ESG principles within the TBL framework. Understanding this relationship is crucial, as businesses seek strategies to enhance sustainability, comply with environmental policies, and maintain profitability [10].

This study aims to bridge the gap by conducting bibliometric analysis of 750 articles published between 2004 to 2024, focusing on key research trends, co-citation networks, and emerging key themes in ESG and green computing. Using VOSviewer and Biblioshiny, we identify the most influential publications, key geographical contributors, and evolving research themes. The findings reveal that China and the United States lead global research output, with a sharp increase in publications post-2018, coinciding with stronger environmental regulations and corporate sustainability initiatives [9,11].

The paper is structured as follows: Section 2 provides a comprehensive literature review, discussing prior research on ESG integration, green computing and the TBL framework. Section 3 outlines the methodology, detailing the bibliometric approach, data collection process, and the analytical techniques used in this study. Section 4 presents the results and key findings, including co-citation analysis, keyword clustering, and geographical research trends. Section 5 offers a discussion of the findings, linking them to theoretical perspectives and practical implications. Finally, Section 6 concludes the paper by summarizing key contributions, highlighting study limitations, and suggesting future research directions.

2. Literature Review

2.1. ESG and Green Computing

The rapid growth of digital technologies has significantly influenced global sustainability efforts, leading to the emergence of green computing – a field focused on reducing the environmental footprint of Information and Communication Technology (ICT) systems [6]. Green computing encompasses several strategies, including energy-efficient hardware, optimized software algorithms, virtualization, and sustainable data center management [2,12]. These approaches aim to reduce carbon emissions, minimize electronic waste, and improve resource efficiency in IT infrastructures. As businesses and industries worldwide move toward net-zero emissions goals, integrating green IT solutions into corporate sustainability strategies has become not only an environmental necessity but also a financial and regulatory imperative [2].

Simultaneously ESG criteria have emerged as a critical framework for corporate sustainability, guiding organizations toward responsible environmental practices, ethical governance structures, and socially inclusive policies [13]. ESG frameworks have gained prominence due to increasing regulatory pressures, investor demands, and shifting consumer preferences toward environmentally responsible businesses [14]. International agreements such as the United Nations Sustainable Development Goals (SDGs) and the Paris Climate Accord have further reinforced the need for businesses to align their operational strategies with ESG and green computing principles [15].

2.1.1. Evolution of Green Computing in ESG Context

Green computing has evolved from a niche concern into a strategic corporate priority, particularly as energy-intensive industries seek to reduce their carbon footprints. Early discussions on sustainable IT practices focused primarily on hardware efficiency and power-saving mechanisms, emphasizing improvements in processor efficiency, low-power computing devices, and energy-conscious software development [16]. However, with the rise of big data analytics, artificial intelligence (AI), and blockchain technologies, the scope of green computing has expanded to include

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sustainable software development, circular economy principles, and AI-driven ESG tracking systems [17].

One of the most significant advancements in green computing has been the development and widespread adoption of cloud computing, which enables businesses to reduce reliance on physical infrastructure, optimize server usage, and minimize overall energy consumption [18]. Major cloud service providers such as Amazon Web Services (AWS), Microsoft Azure, and Google Cloud have committed to achieving carbon neutrality by investing in renewable energy-powered data centers [19]. Similarly, innovations in edge computing have enabled companies to process data closer to the source, reducing network energy consumption and enhancing real-time analytics, which is particularly beneficial for industrial applications and Internet of Things ecosystems [20].

In addition to cloud and edge computing, AI driven energy management system have further revolutionized green computing by dynamically adjusting IT infrastructure power, usage, predicting workload demands, and automating ESG compliance tracking [21]. These AI-powered solutions allow businesses to optimize their energy consumption while maintaining computational efficiency, demonstrating that green computing is no longer just an environmental initiative but an essential component of ESG-aligned corporate strategy.

2.2. ESG in Business Sustainability and Green Computing Adoption

Green computing has become an integral part of ESG adoption as companies seek ways to align their technology investments with sustainability goals. Industries such as finance, healthcare, and retail are increasingly leveraging sustainable computing models to improve efficiency while maintaining ESG compliance [21]. The finance sector, for example, has adopted blockchain technology to enhance ESG tracking, improve supply chain transparency, and facilitate carbon credit verification [22]. Similarly, healthcare organizations are utilizing cloud-based electronic medical records (EMR) and AI-driven patient monitoring systems to reduce unnecessary data storage and enhance resource efficiency, leading to lower carbon emissions and optimized healthcare operations [18].

From a governance perspective, ESG – aligned green computing policies require organizations to implement responsible e-waste disposal, IT lifecycle management, and regulatory compliance in digital operations [23]. As part of this transition, governments and regulatory bodies have introduced green IT policies aimed at encouraging companies to adopt sustainable digital [24]. In the European Union, the Green Deal and CSRD have introduced strict ESG reporting standards, requiring businesses to disclose energy consumption and environmental impact across their IT infrastructures [25]. Likewise, China's Green Data Center Initiative has set ambitious targets to make 80% of IT facilities energy-efficient by 2030 [26]. These policies underscore the increasing role of regulatory frameworks in accelerating green computing adoption within ESG-driven business strategies.

The role of corporate leadership and stakeholder engagement is also critical in ensuring the success of green computing initiatives. Many companies are incorporating sustainable objectives into their corporate governance frameworks, linking executive compensation to ESG performance metrics and publishing annual sustainability reports detailing their IT energy consumption, carbon reduction strategies, and environmental impact [7,27,28]. These efforts demonstrate that green computing is not only an operational shift but also a governance commitment that requires active involvement from business leaders, policymakers, and investors.

2.3. Research Gaps and Future Directions

Despite the rapid development of green computing and ESG integration, several challenges remain unaddressed. One of the primary challenges is the lack of standardized ESG measurement frameworks for IT sustainability. Many companies struggle to quantify the direct impact of their IT operations on ESG goals due to the absence of universally accepted key performance indicators (KPIs) [29]. While sustainability reporting frameworks such as Global Reporting Initiative (GRI) and Task

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Force on Climate-Related Financial Disclosures (TCFD) provide some guidelines, they do not specifically account for the complexity of green computing initiatives in different industries.

Another major challenge is the implementation barriers faced by small and medium-sized enterprises (SMEs). While large corporations have the financial and technological resources to adopt sustainable computing models, SMEs often lack access to cost-effective green computing solutions and face difficulties in securing funding for energy-efficient IT infrastructure [30]. Additionally, the cost-benefit analysis of green computing remains unclear for many organizations, particularly in industries where IT operations are not the primary driver of business performance.

Furthermore, cybersecurity risks associated with sustainable IT infrastructure present an emerging concern. As companies increasingly rely on cloud-based and decentralized computing systems for ESG tracking and reporting, they become more vulnerable to cyber threats and data breaches [31]. Strengthening data protection measures while ensuring sustainable IT infrastructure remains cost-effective will require future research into advanced encryption, decentralized cloud security protocols, and AI-driven threat detection for ESG-related IT ecosystems.

Given these challenges, future research should focus on developing ESG metrics that integrate green computing indicators for standardized reporting. Additionally, further studies should explore AI-driven solutions for automated ESG compliance and sustainability tracking, enabling businesses to monitor their environmental impact in real time. Longitudinal studies assessing the long-term economic impact of sustainable computing investments across different industries would also provide valuable insights for corporate decision-making.

As ESG regulations continue to evolve, businesses must proactively embrace green IT innovations to maintain regulatory compliance, improve operational efficiency, and enhance long-term sustainability performance [10]. By leveraging the latest advancements in AI, blockchain, and cloud computing, organizations can integrate green computing into their ESG strategies, ensuring both environmental responsibility and financial resilience in an increasingly sustainability-driven global economy.

3. Methodology

Bibliometric analysis methods were employed to synthesize the existing literature, leveraging data from the Scopus database [21]. Bibliometric research involves quantitative and statistical techniques applied to bibliographic data [27,32]. This includes methods such as descriptive statistical analysis, performance and cluster analysis, and science mapping. Performance mapping measures publication and citation-related variables, while science mapping examines the impact and relationships among various article attributes, such as co-occurrence weight and total strength [33–36]. Techniques like citation analysis, co-citation analysis, bibliographic coupling, keyword, and co-authorship analysis were utilized in his research.

Data for this study were retrieved from the Scopus database in May 2024. Established in 2004, Scopus is an international bibliographic database providing abstracts and citations for academic publications from reputable scientific journals. It includes over 36,377 from 11,628 publishers and 34,346 peer-reviewed journals in science, technology, medicine, humanities, arts, and social sciences [28].

Research of the Scopus database using terms such as “ESG,” “Triple Bottom Line,” and “business development” yielded 53 initial results. The final search formula: (“ESG performance” OR “sustainability”) AND (“green computing” OR “sustainable computing” OR “green IT”) AND (“triple bottom line” OR “TBL” OR “sustainable development”) resulted in 750 articles. The analysis, covering publications from 2004 to 2024, utilized VOSviewer and Biblioshiny for data visualization and analysis, as Figure 1 shows.

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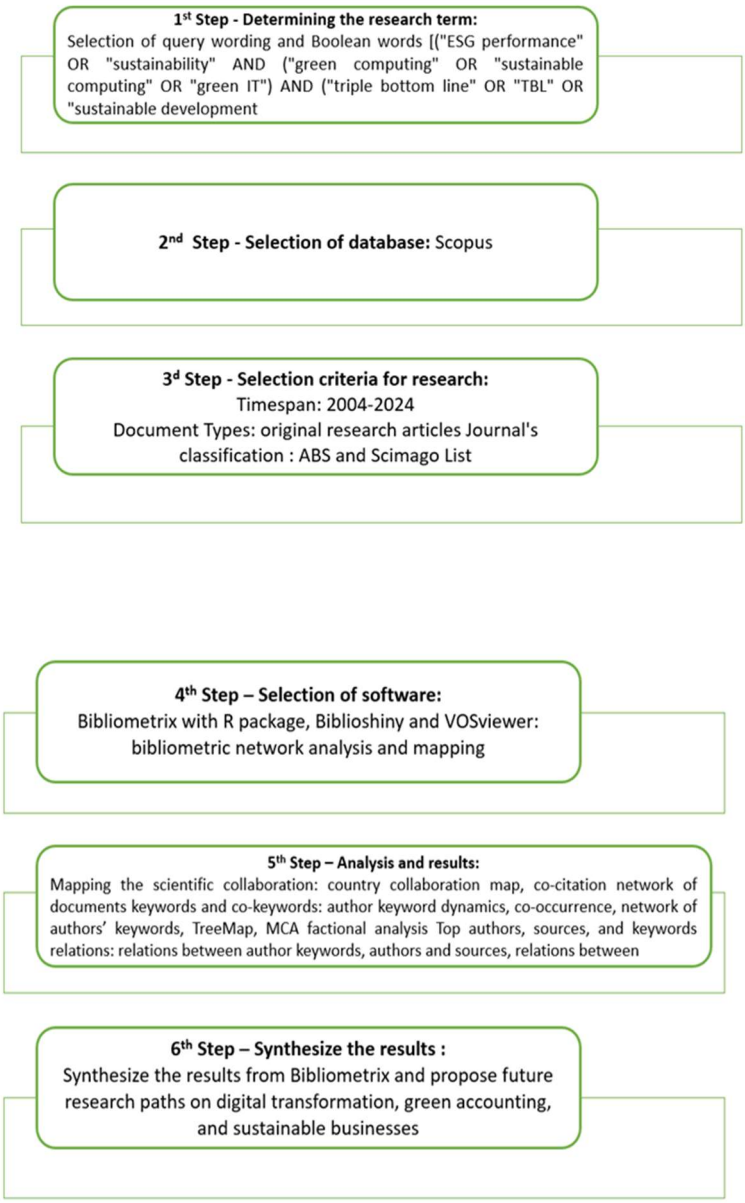

Figure 1. Flow of Methodology.

4. Results

4.1. Evolution of the Numbers of Articles

Figure 2 illustrates the annual scientific production related to the subject area studied from 2004 to 2024, based on 750 articles. The data reveals an overall upward trend in publications annually, indicating a growing interest and research activity in these fields. From 2004 to 20008, articles were relatively low, starting near zero, reflecting the nascent stage of ESG awareness, which gained prominence following the UN Global Compact's "Who Cares Wins" report in 2004 [37]. The integration of ESG and green computing began to gain momentum around 2010, driven by increasing recognition of sustainable business practices and stakeholder pressure for environmental and social accountability [38,39].

A noticeable increase in publications occurred around 2008, peaking in 2011, attributed to heightened awareness and rigorous research efforts in sustainability and green computing. The

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global economic crisis of 2007-2009 further underscores the importance of corporate sustainability, leading to increased scholarly attention [30].

From 2018 onwards, there was a significant rise in article production, peaking in 2022. This surge reflects the global emphasis on sustainability, environmental regulation, and integrating ESG principles into corporate strategies. Research highlights, such as those by [11] demonstrate that ESG performance significantly impacts green innovation, particularly in the Chinese industrial sector, enchanting innovation, en-chasing green innovation by alleviating financial constraints, and improving human capital. The peak in 2023 aligns with the heightened focus on sustainable development and the creation of the TBL project, which is critical for assessing nations' economic development beyond traditional economic measures [5].

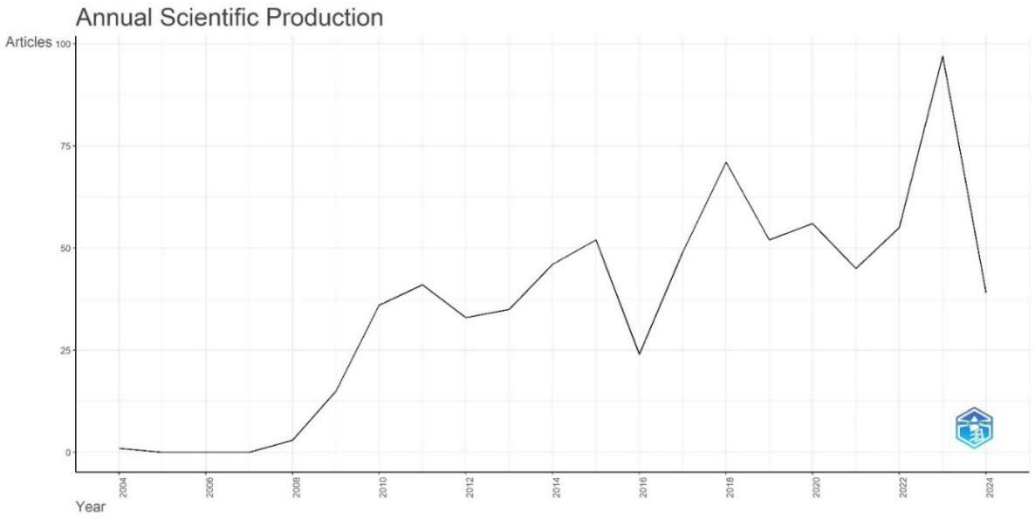

Figure 2. Annual production of Scientific areas on Green Computing and ESG by Biblioshiny.

Figure 3 organizes sources into 7 clusters, highlighting the Journal of Sustainability, MIS Quarterly, and the Journal of Cleaner Production as the top 3 Journals with the most research on ESG and Green computing affecting the TBL.

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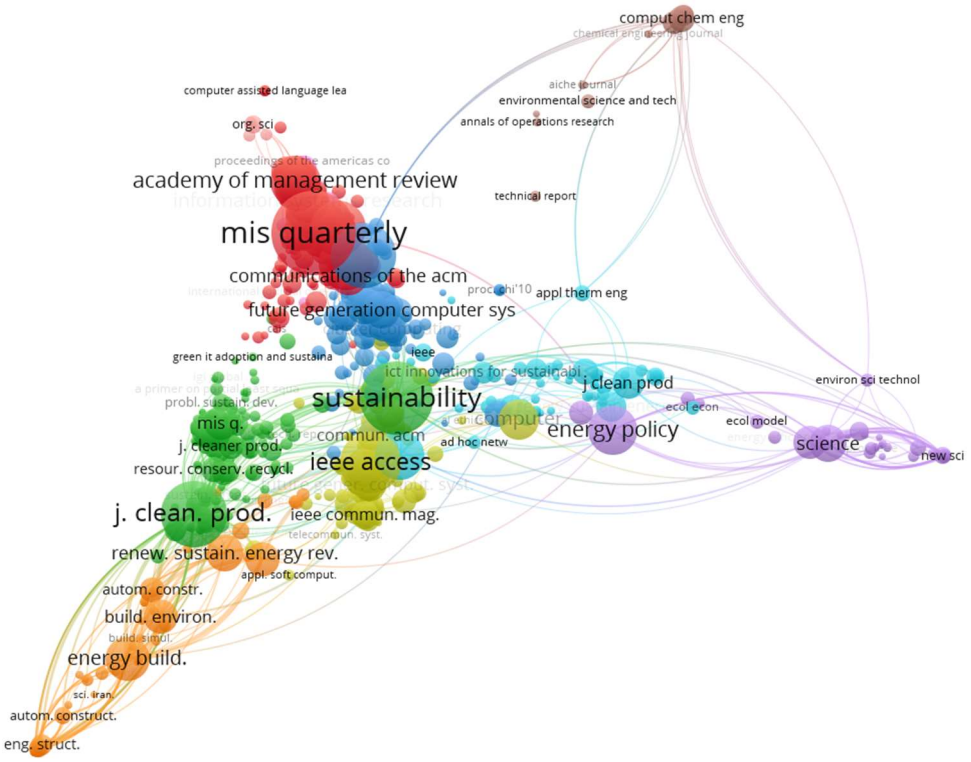

Figure 3. Co-citation Analysis Map of Key publications on ESG, Green Computing, and their Contribution to the TBL Using VOSviewer.

4.2. Geographical Collaboration Analysis

Figure 4 presents the global distribution of scientific publications related to ESG and green computing, emphasizing their contributions to the TBL. The data shows that the USA is leading with 401 documents, reflecting a strong focus on sustainability and technological innovation. Studies by [31,41] highlight the significance of transparent ESG practices in enhancing performance and economic development. Other key contributors include China. Demonstrating broad international engagement in integrating ESG principles and green computing for enhanced performance. Min-Jae Lee's research underscores the impact of ESG and green computing on the TBL of Chinese companies [24].

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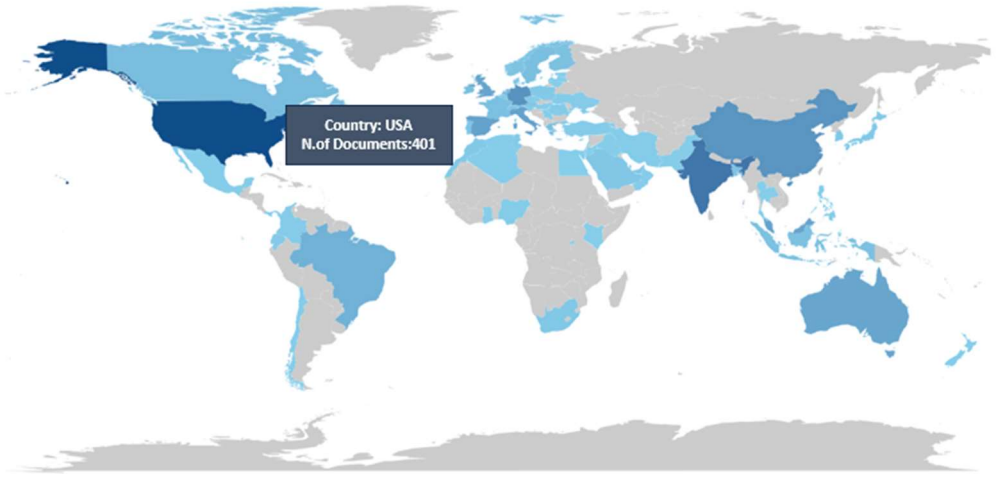

Figure 4. Scientific Output of Leading Countries on Green Computing and ESG Contributions to the TBL, by Biblioshiny.

Figure 5 illustrates regional collaboration among experts on the research topic of how ESG and green mapping boost the TBL, which Biblioshiny created. Brown lines crisscross the map, connecting various countries and representing collaborative links between them. The density and number of these lines indicate the extent and strength of these collaborative relationships. The United States stands out as a central hub for international research collaboration, with numerous lines extending mostly to Europe and China European countries also display dense interconnections, suggesting strong international collaboration.

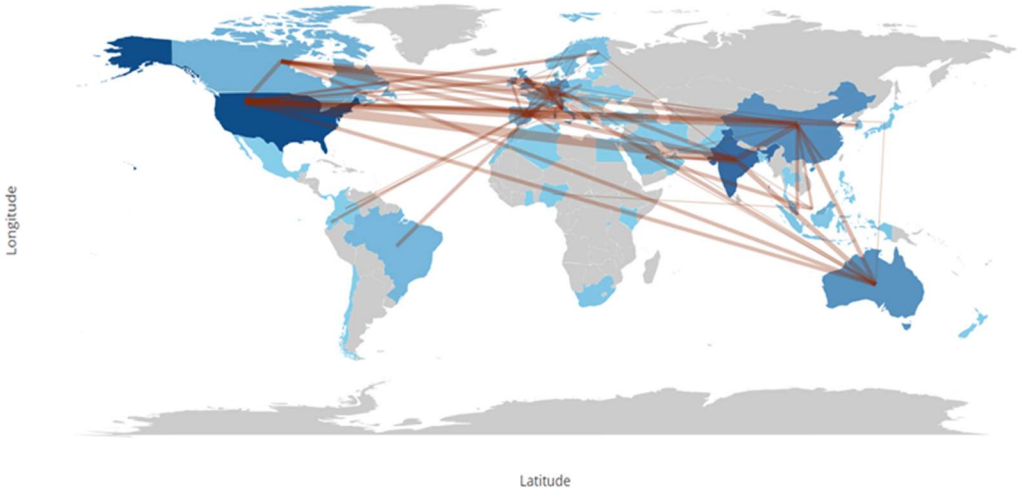

Figure 5. Map of Country Collaborations by Biblioshiny.

4.3. Keyword Analysis

The authors keyword analysis helps researchers and research engines locate relevant publications. This analysis can boost the paper's readership and citations, reveal research trends, and identify gaps [28,35,36]. Figure 7 shows the Word Treemap with the top 50 keywords in ESG and green computing research from 2004 to 2024. "Sustainable development" dominates the map with

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717 occurrences (19%), reflecting its central role in research. The TBL framework emphasizes sustainability in value-creation activities, boosting economic growth and competitiveness [5,41–43].

Figure 7. Word TreeMap by Biblioshiny.

Moreover, the critical role of sustainability and green computing and their impact on the TBL is highlighted in Figure 8. This figure highlights the co-occurrence of author keywords, using VOSviewer to create and visualize bibliometric networks. Each circle represents keyword occurrences, with larger circles indicating higher co-occurrence. Keywords are organized into clusters, which indicate their connections. The articles' similar color denotes keyword clusters, while the line linking the circles shows keyword relationships. 86 were separated into 7 clusters, each with a distinct hue. Yellow and purple clusters represent green IT and data center-related terms and suggest a focus on the intersection of IT and sustainability practices, exploring how IT can be leveraged to achieve environmental goals. The light blue and green clusters are related to energy efficiency terms and emphasize optimizing energy use, improving efficiency, and integrating renewable energy sources within various technologies. Red and orange clusters represent Environmental impact and measurement-related items. Finally, the blue cluster includes sustainability-related terms and focuses on designing, developing, and managing software in the most environmentally friendly way possible.

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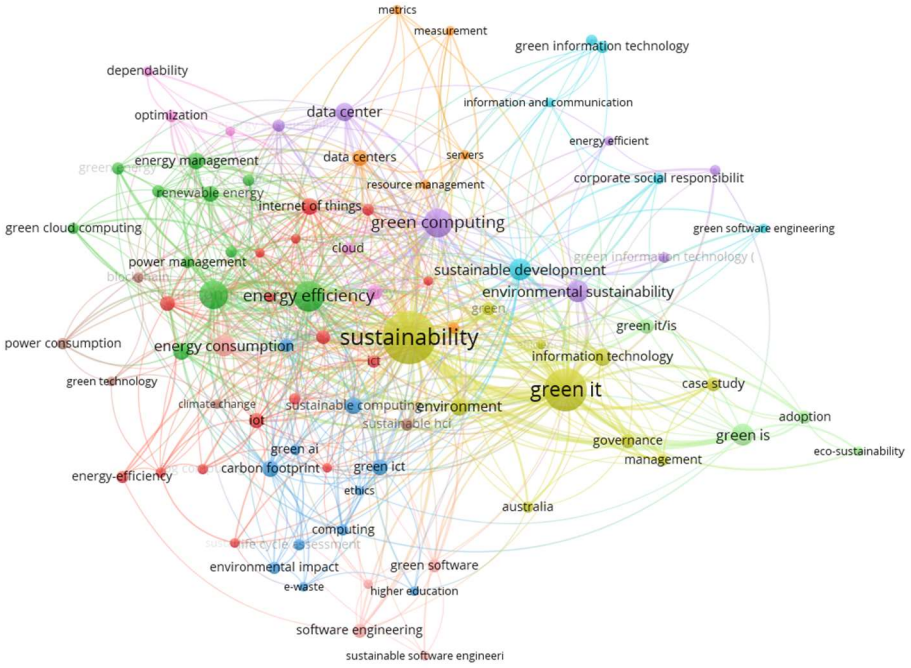

Figure 8. Visualization of co-occurrence of author keywords by VOSviewer software.

Figure 9 shows the research themes derived from the bibliometric analysis. The map is divided into four quadrants. Motor themes (upper right) are well-developed and highly relevant. Basic themes (lower right) are foundational but underdeveloped. Niche themes (upper left) are specialized but not central. Though not yet fully developed, these themes are foundational and essential to the field. These thematic map themes of ''sustainable development'', ''green computing'', and ''energy efficiency'' are potioned in this field, emphasizing their core importance but indicating the need for further research and development to fully integrate them into the research. According to [39], there will be many studies on green computing and its impact on sustainable development.

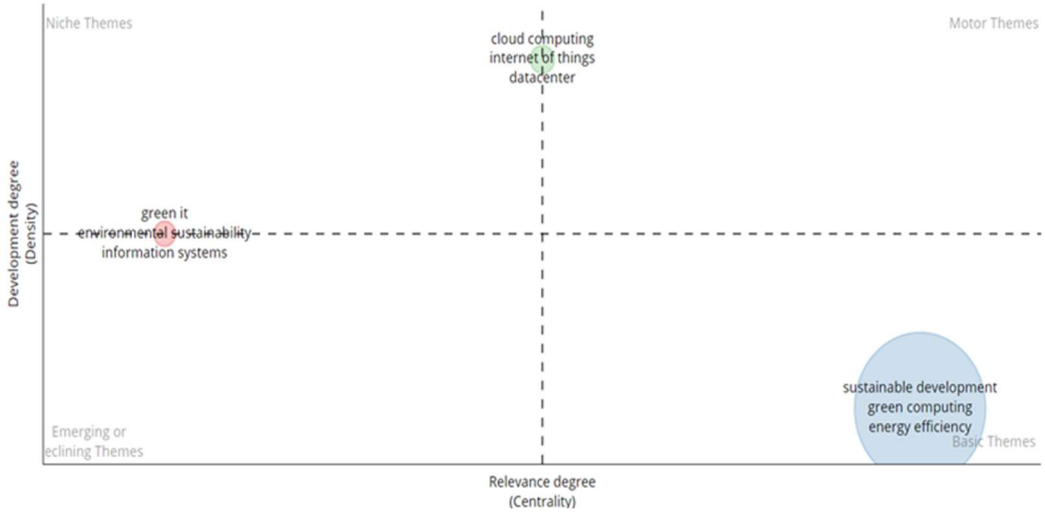

Figure 9. Research themes derived from bibliometric analysis.

Finally, Figure 10 illustrates the findings of the Multiple Correspondence Analysis (MCA) performed using VOSviewer software. Keywords close together are more related, with a red polygon indicating significant relationships. Keywords like "Internet of Things," "renewable energy

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resources," and "sustainable computing" are clustered together, suggesting that they frequently co-occur. Technological keywords like "cloud computing," "data centers," "information technology," and "software engineering" are interrelated in the context of sustainable practices and green IT. Energy efficiency is a key focus for creating sustainable networks, with computing technology enchasing performance computing and storage solutions [23].

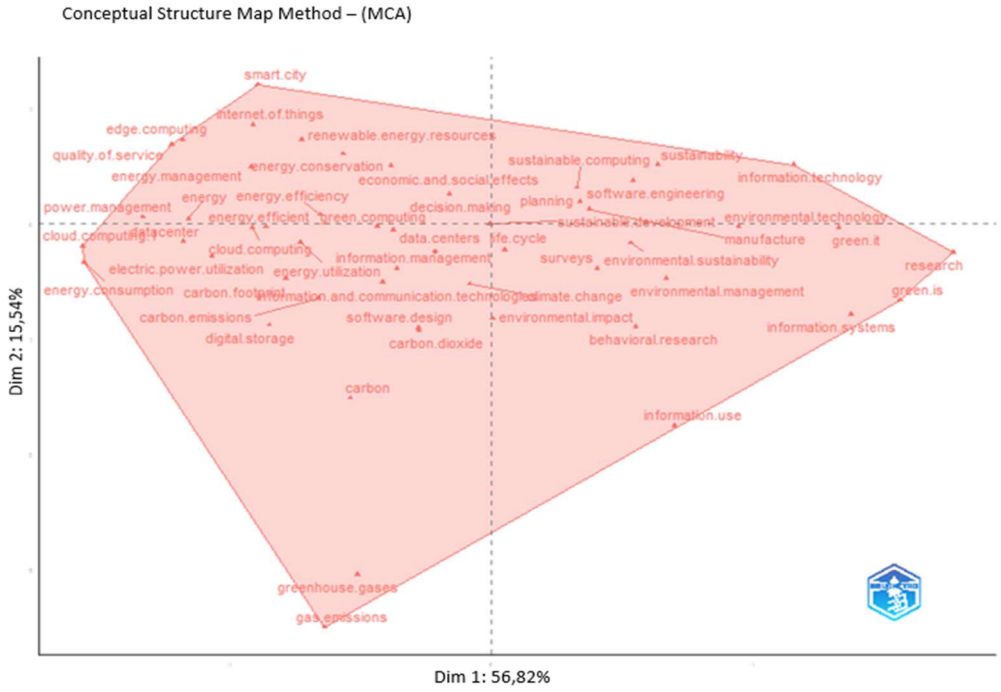

Figure 10. Multiple Correspondence Analysis (MCA) using VOS viewer.

5. Discussion

The results of this study indicate a clear upward trend in research on ESG and green computing, reflecting the growing corporate and regulatory emphasis on sustainability-driven digital transformation. The increase in annual publications, particularly after 2015, suggests that ESG integration and sustainable IT practices have become mainstream topics in academic research and business policies.

The most influential studies identified in this analysis provide a strong foundation for understanding the intersection of ESG and green computing. Research by [20,21] highlights the environmental benefits of AI-powered energy optimization and cloud computing, while works by [14] emphasize the financial and governance aspects of ESG-aligned IT strategies. These findings align with the argument that green computing is no longer a purely technical concern but a fundamental component of corporate ESG strategies.

The keyword co-occurrence analysis reveals that corporate social responsibility (CSR), energy efficiency, and regulatory compliance are among the most frequently studied topics in ESG and green computing research. This suggests that organizations are not only focused on adopting greener IT solutions but also ensuring that these solutions align with broader ESG goals, financial performance, and compliance requirements. These findings are consistent with prior studies demonstrating that companies integrating ESG-focused IT governance outperform those that do not in terms of risk management and investor confidence [17,45].

The geographical analysis shows that China and the United States dominate research output, likely due to the strong policy support and high corporate investment in sustainable IT infrastructure in these regions. While lower in volume, European contributions reflect a policy-driven approach

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where stringent regulatory requirements influence research focus areas. The collaboration networks indicate a growing globalization of ESG and green computing research, reinforcing the need for cross-border cooperation in sustainable digital transformation.

Despite these advances, there are still gaps in ESG and green computing research. The results suggest that while environmental and governance-related themes are well-explored, there is less emphasis on social sustainability aspects, such as ethical sourcing in IT hardware, labor conditions in supply chains, and digital inclusivity. Addressing these gaps will be crucial for advancing a more holistic ESG-driven approach to sustainable computing.

6. Conclusions

This study provides a comprehensive bibliometric analysis of the ESG integration and green computing research landscape over the past two decades, highlighting key trends, influential contributions, and thematic clusters. The results indicate that research in this field has experienced substantial growth, particularly since 2015, reflecting the increasing corporate and regulatory focus on sustainable IT practices. The analysis of citation patterns and co-occurrence networks reveals that energy efficiency, ESG governance, and corporate social responsibility (CSR) are among the most frequently explored topics, underscoring the role of green computing as a fundamental component of ESG strategies.

The keyword analysis identified three major research clusters: corporate ESG strategies, green computing innovations, and regulatory perspectives. The first cluster focuses on integrating ESG frameworks into business models and IT governance, highlighting how organizations align their digital transformation efforts with sustainability goals. The second cluster examines technological advancements in green computing, including AI-driven energy management systems, cloud computing efficiency, and sustainable IT infrastructures. The third cluster pertains to government regulations and policy frameworks, crucial in shaping corporate sustainability initiatives. The geographical analysis further reveals that China, the United States, and Europe dominate research output, with notable collaborations among leading institutions such as Tsinghua University, MIT, and Cambridge University.

The findings of this study reinforce the argument that green computing is no longer just technical innovation but a strategic imperative for businesses and policymakers. The alignment of sustainable IT solutions with ESG principles enhances financial performance, reduces environmental impact, and improves corporate governance standards. Organizations that adopt energy-efficient IT infrastructures and transparent ESG reporting mechanisms gain a competitive advantage as investors and stakeholders increasingly prioritize sustainability metrics in decision-making. Moreover, regulatory frameworks such as the EU's Corporate Sustainability Reporting Directive (CSRD) drive corporations toward greater accountability in ESG implementation, further solidifying the need for green IT governance [25].

Despite these achievements, this study also identifies significant research gaps warrant further investigation. While much of the existing literature focuses on environmental and governance aspects of ESG, there is relatively less emphasis on the social dimension, particularly in areas such as ethical sourcing of IT components, digital inclusivity, and labor rights in technology manufacturing. Future research should explore how green computing can contribute to social equity, particularly in emerging economies with limited access to sustainable digital infrastructure. Additionally, the economic impact of green computing on SMEs is an underexplored area that deserves further study.

This study acknowledges the limitations of bibliometric analysis, particularly in capturing the qualitative dimensions of ESG integration in IT governance. Bibliometric techniques rely on quantitative citation-based metrics, which may not fully reflect the practical impact of green computing initiatives on businesses and society. Future studies could complement bibliometric findings with qualitative methodologies, expert interviews, and case studies to provide a more holistic understanding of the field. Expanding the dataset to include multiple bibliographic sources,

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such as Web of Science and IEEE Xplore, would also enhance the scope and reliability of future bibliometric analyses.

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