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Green Technology for Business: A Bibliometric Analysis

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ABSTRACT

Green technology has gained prominence this decade since the core of green technology preserves the resources and the environment while enhancing business sustainability. However, few pieces of research present literature reviews of the application of green technology for business despite its importance in providing the map of a conceptual framework for identifying research gaps, inconsistencies in prior studies, and the "state-of-the-art" snapshot domain for future research. The research contributed to the limited literature reviews regarding the application of green technology in business research by using a novel approach, which was bibliometric analysis. The research aimed to provide evidence of collaboration between authors and the most influential countries related to applying green technology for business research using co-authorship analysis. It also analyzed the knowledge structure of this topic and determined the primary and emerging issues through co-word analysis. Furthermore, the research performed the analysis of co-citation to identify the intellectual backbone of this research domain. On top of that, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach was used to provide better accuracy in identifying and extracting the data for a bibliometric review. As the result, the research finds 735 journal articles related to green technology for business research from 1995 to 2020. In addition, four clusters are found to describe the current state of green technology for business research: environmental performance, circular economy, sustainable development, and climate policy. Then, research trend is also proposed to guide potential areas for further research to ascertain that the researchers have an inclusive insight on this topic.

Keywords: green technology, business, bibliometric analysis

INTRODUCTION

Global climate change has become a significant issue since it determines how people can survive while the environment continues to degrade. Individuals, organizations, communities, and nations need to reconsider how to produce, consume, and use products, services, and technology as mitigation actions (Ferreira, Fernandes, & Ferreira, 2020). This increasing awareness of global climate change leads to the prominence of green technology since the core of green technology is preserving the resources and the environment while enhancing the business sustainability (Guo, Xia, Zhang, & Zhang, 2018; Ishak, Jamaludin, & Abu, 2017). For instance, Green Information Technology (Green IT) facilitates organizations to achieve eco-efficiency by applying hardware and software with capabilities to reduce energy consumption and carbon emissions (Cai, Zheng, Cai, Yang, & Comite, 2021). In addition, green technology investments and sustainability engagement have a positive relationship (Saunila, Rantala, Ukko, & Havukainen, 2019).

Several prior studies present insight into the drivers that facilitate green technology investment. For example, there are environmental regulations

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(Hall, Matos, & Bachor, 2019), customer pressure (Chu, Wang, & Lai, 2019), managerial concerns (Tang, Walsh, Lerner, Fitza, & Li, 2018), managers' personal value (Dalvi-Esfahani, Ramayah, & Rahman, 2017), and profit maximization (Song, Wang, & Sun, 2018). However, few researchers present literature reviews on the application of green technology for business despite its importance in providing the map of the conceptual framework for the identification of gaps in research, inconsistencies in prior studies, and "state-of-the-art" snapshot domain for future research (Palmatier, Houston, & Hulland, 2018).

Prior research has presented an overview of Green IT/ Green Information System (Green IS) adoption in organizations (Esfahani, Shahbazi, Nilashi, & Samad, 2018). They have applied the Systematic Literature Review (SLR) method to summarize the prior studies on adopting Green IT/IS within the organization. Furthermore, they have used the Upper Echelon Theory (UET) in formulating the research questions. SLR can support them in detecting the areas that can be developed further. However, SLR is vulnerable to validity threats, such as publication and study selection bias and data extraction bias, which directly affect the result (Snyder, 2019).

Moreover, previous research explains how organizations utilize Green IT to promote organizational sustainability (Chong & Olesen, 2017). They have used meta-analysis and Technology-Organization-Environment (TOE) model. They have also collected previous studies to examine the predictors of the TOE model and ensure their relative strength and impacts. Their meta-analysis can guide future researchers and practitioners because they provide a set of factors that influenced Green IT implementation in companies. However, they have only included papers that apply correlation analysis. Therefore, for some variables, the data are not sufficient for meta-analysis. Furthermore, meta-analysis cannot handle heterogeneity between studies, which leads to misleading results (Rhodes et al., 2018).

Bibliometric analysis is applied to address those issues. It is one of the quantitative approaches to describe, assess, and monitor the published research to present a systematic and objective review process. Then, it enhances the quality of reviews (Zupic & Čater, 2015). It is more practical and easier to examine and analyze unlimited quantities of papers (Feng, Zhu, & Lai, 2017) and scale from micro to world level (Batistič & Laken, 2019). Furthermore, it can also prevent subjective assessment of narrative literature review methods because it has a functional aid in literature reviews by mapping the research field that is directly extracted from the documents (Zupic & Čater, 2015). However, no studies investigate the primary themes regarding green technology application in business research using bibliometric methods, such as co-authorship analysis, co-word analysis, and co-citation analysis. Hence, the research aims to fill this gap by analyzing the global trends and scholarly networks on this topic.

Co-authorship analysis is one of the bibliometric methods which is powerful in determining prolific scientists and the most influential countries. The analysis reveals the leading actors and their connections. It is widely used to identify research domains (Fonseca, Sampaio, Fonseca, & Zicker, 2016). Meanwhile, the co-word analysis explores the relationship among keywords by looking at the co-occurrence of pairs of keywords. Then, frequency analysis is the foundation of co-word analysis, in which the more co-occurrence between two keywords are, the closer their relationship is (Guo, Chen, Long, Lu, & Long, 2017). Finally, the co-citation method will complete the analysis by providing the intellectual structure of a research domain (Cillo, Petruzzelli, Ardito, & Giudice, 2019). These three analyses give a better insight related to the topic by finding collaboration trends among researchers and providing a conceptual structure to show the current research status and guidance for future research.

The research aims to provide evidence of collaboration between authors and the most influential countries related to applying green technology for business research using co-author analysis. It also analyzes the knowledge structure and domain of this topic and determines the primary and essential themes of the field through co-word analysis and co-citation analysis. It ascertains that the future researchers thoroughly understand the green technology research trends. Hence, the research contributes to the literature on green technology application in business by providing a reference for development in this area, offering a map of the current research status, and providing guidance on potential areas for further research.

METHODS

The research implements the guidelines from Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) to identify and extract the data for a bibliometric review (Maier, Maier, Aşchilean, Anastasiu, & Gavriş, 2020). The first step of the PRISMA approach is identifying articles related to the topics. The research extracts the data from the Scopus database to obtain bibliographical records related to green technology for business. Scopus is the biggest database of abstracts and citations of peer-reviewed literature. It is trustworthy, authoritative, and frequently used for searching the literature (Baas, Schotten, Plume, Côté, & Karimi, 2020). Then, the research uses journal articles only as data since they have already passed rigorous review processes given by several experts in the field before being published in an academic journal. Moreover, the research performs a search query related to the topic to find relevant articles. The search query is TITLE-ABS-KEY ("green technolo*" OR "clean technolo*" OR "eco technolo*" OR "green innovat*" OR "clean innovat*" OR "eco innovat*" OR "low carbon technolo*" OR "low carbon innovat*" OR "green IT"

OR "green information system*" AND "business"). By performing the search string in the Scopus database, there are 1.379 academic papers. In the next step, the research eliminates journal articles which are not written in English. This process indicates that 735 English journal articles published between 1995 and 2020 are used. The data collection and data analysis process can be seen in Figure 1.

The research applies bibliometric analysis, consisting of co-authorship, co-word, and co-citation analysis. First, co-authorship analysis shows collaboration patterns between individuals and countries (Youngblood & Lahti, 2018). There are several steps in co-authorship analysis: retrieving the scientific publications, visualizing the network and calculating the metrics, and interpreting the results (Fonseca et al., 2016). In this stage, VOSviewer version 1.6.11 software is used to calculate the metrics and provide network visualization. In co-authorship networks, nodes represent authors or countries, which are connected when they share the authorship of a paper (Fonseca et al., 2016).

Second, the co-word analysis examines the current state of the research topic. It explores the relationship among keywords by looking at the co-occurrence of pairs of keywords. There are several procedures performed in co-word analysis. It counts the frequency of the keywords and detects and removes the duplicate and misspelling items. After that, it removes the keywords with less than eight frequencies because they imply only a few researchers who pay attention to them (Chen, Chen, Wu, Xie, & Li, 2016). Next, it selects high-frequency keywords and gathers them in clusters. The last step is to interpret the knowledge structure of topics represented by social network analysis.

Third, the following bibliometric analysis is co-citation analysis. It can be defined as the frequency of two documents cited together in other documents. The process of co-citation analysis is divided into four steps: (1) relevant academic papers identification, (2) similarity calculation between pairs of reference papers through co-citation counts, (3) co-citation calculation of the papers using through similarity values, and (4) result interpretation (Hota, Subramanian, & Narayanamurthy, 2020).

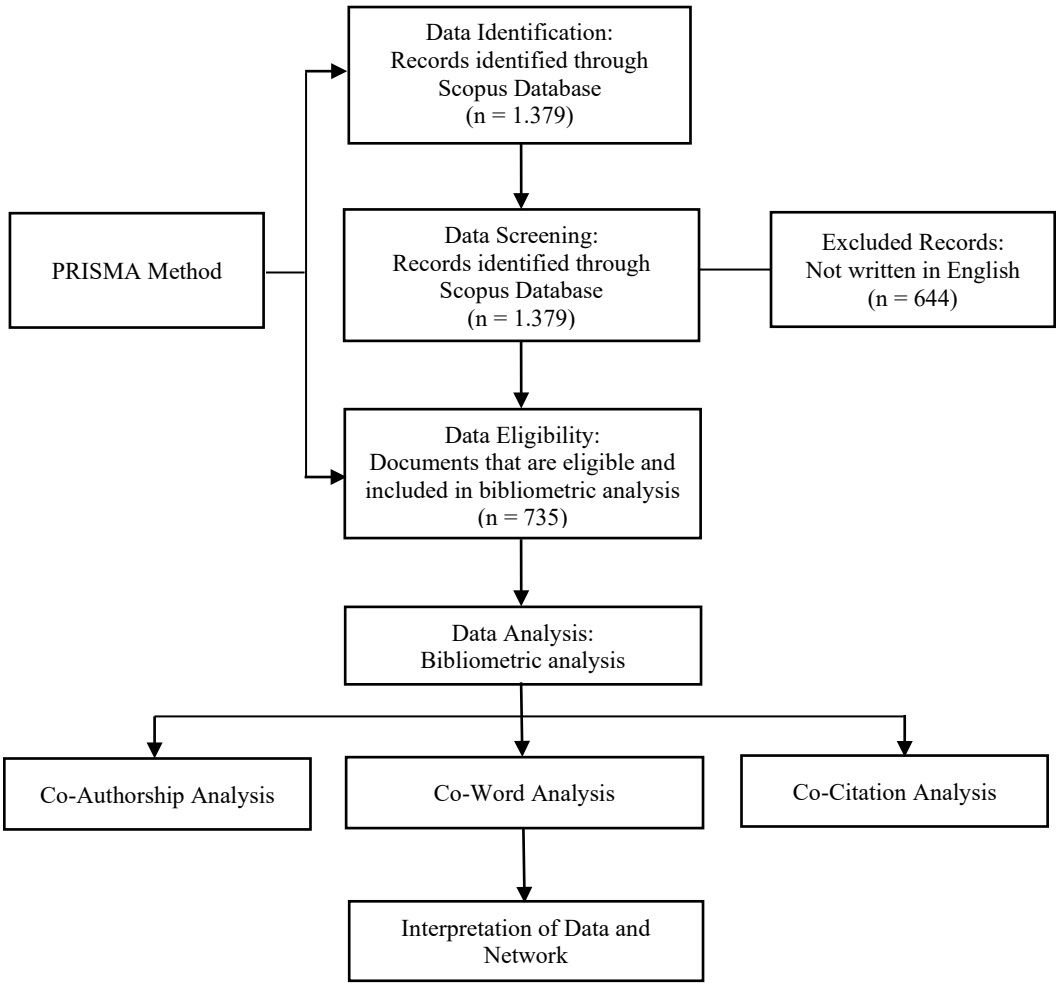

Figure 1 Research Methodology

RESULTS AND DISCUSSIONS

The research starts by discussing the trends of publication activities which are analyzed to illustrate the evolution of green technology for business research. The first research publication on green technology for business was in 1995. Since then, the application of green technology in business research has gained ground due to increasing attention toward climate change. It can be seen from Figure 2 that the study of green technology in the business has increased gradually from year to year, which reached its peak at 91 articles in 2019.

Next, the co-authorship analysis illustrates the authors and countries participating in green technology for business research. Figure 3 shows the co-authorship network that VOSviewer establishes to visually present the collaborations between authors. As illustrated in Figure 3, few networks exist between the authors in this field. It also can be seen that the most prolific author in terms of publication count is Scarpellini S. with nine documents and the biggest node, which is followed by Wang S. with seven papers. Table 1 depicts the most productive authors in green technology for business research.

From Table 1, it can be concluded that Scarpellini S. is the most productive researcher in green technology for business research. Most of publications by Scarpellini S. focus on dimensions of eco-innovation business (Scarpellini, Valero-Gil, & Portillo-Tarragona, 2016; Scarpellini, Portillo-Tarragona, & Marin-Vinuesa, 2019; Scarpellini, Valero-Gil, Moneva, & Andreaus, 2020). The author highlights that environmental management system, eco-innovation in Human Resource (HR) policy, corporate governance policy, and environmental management accounting are the determinants of firms' circular eco-innovation.

For the citations, Chen Y.S. ranks first with 1.286 citations. The most cited article by Chen Y.S is entitled "*The Influence of Green Innovation Performance on Corporate Advantage in Taiwan*" (Chen, Lai, & Wen, 2006), with 591 citations. It has examined the cause-effect relationship between green innovation and competitive advantage. In general, Chen Y. S. focuses more on the green innovation-related variables to induce the business' competitive advantages, such as green product innovation, green intellectual capital, green process innovation, and green innovation performance (Chen, 2008; Chen et al., 2006; Chen & Chang, 2013).

Moreover, the research domain can be identified by countries analysis. By understanding the countries with a high concentration of green technology for business, the research is useful for investigating the patterns and trends of the research domain (Abeydeera, Mesthrige, & Samarasinghalage, 2019). Figure 4 depicts the country network analysis. Based on Figure 4, the United States and China are the major contributors to green technology for business research since they have the largest nodes, with 107 and 76 articles, respectively. They are followed by the United Kingdom with 72 articles. Then, Table 2 depicts the details of the analysis of the most productive authors in producing green technology for business research.

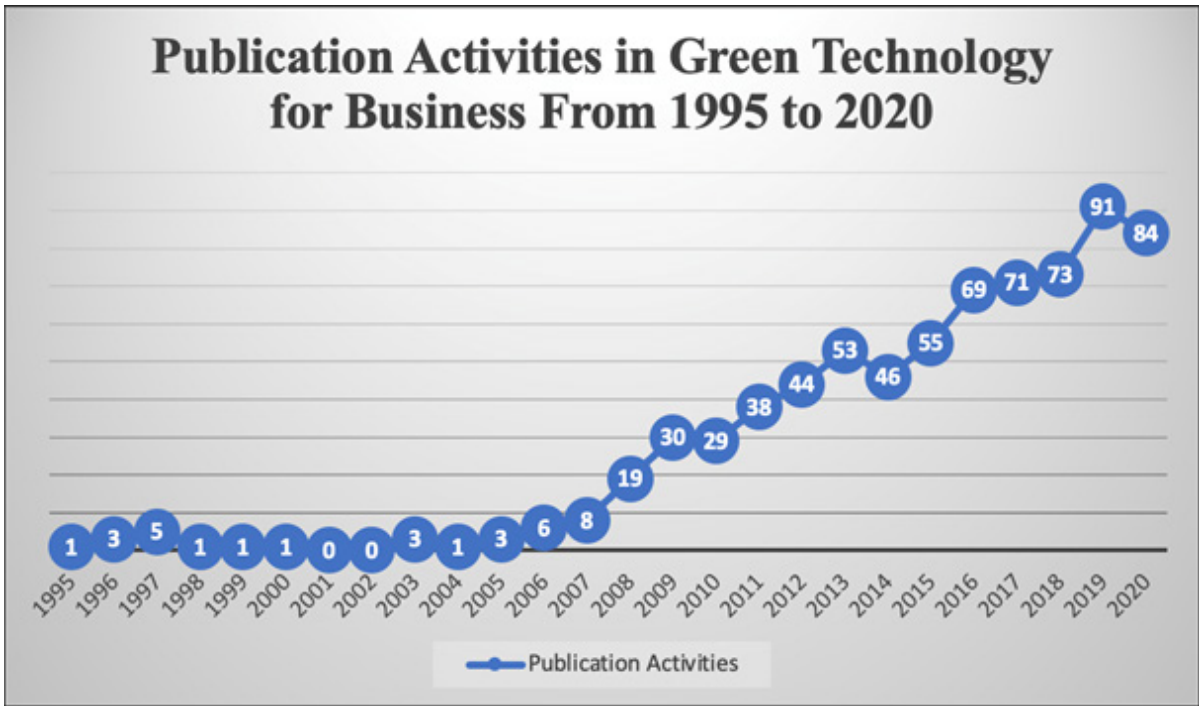

Figure 2 Green Technology Trends for Business Research

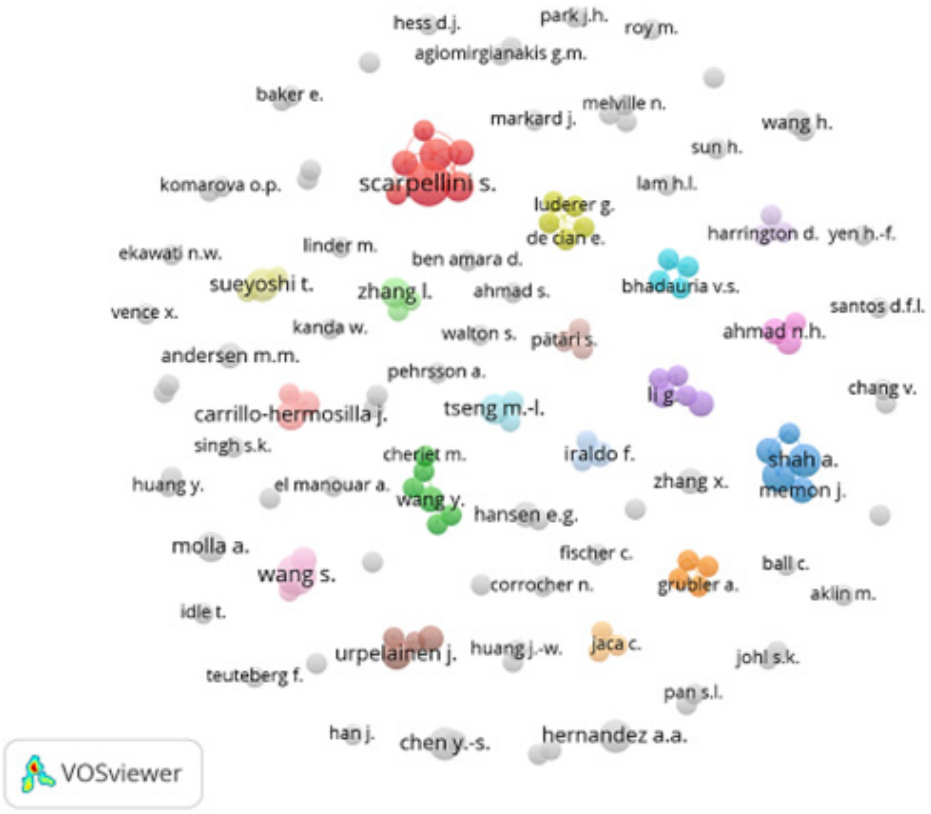

Figure 3 Network Visualization of Co-Authorship Analysis by Authors

Table 1 Co-Authorship Analysis of Most Productive Authors on Green Technology for Business Research

Author	Documents	Rank	Citations
Scarpellini S.	9	1	87
Wang S.	7	2	93
Portillo-tarragona P.	5	3	70
Shah A.	5	3	183
Uddin M.	5	3	183
Sueyoshi T.	5	3	47
Chen Y. S.	5	3	1.286
Hernandez A. A.	5	3	25

According to Table 2, the United States and China are the main contributors to green technology for business research based on the number of articles produced. The main topic of green technology for business research in the United States is related to the government policies or regulations which promote green technology innovation (Goldstein, Doblinger, Baker, & Anadón, 2020; Klemun, Edwards, & Trancik, 2020). Furthermore, prior studies have also examined the relationship between green innovation technology and organizational performance (Amoon & Tobely, 2019; Gossart, Özaygen, & Özman, 2020). On top of that, previous research in the United States has also measured the impact of green technology innovation on firms' decision-making processes (Dotzel & Faggian, 2019). Meanwhile, in China, prior studies have focused on the relationship between green innovation and sustainability (Li et al., 2020; Ma et al., 2020), the role of leaders in developing green innovation (Su et al., 2020), government policies in promoting green innovation (Liu, Jiang, & Bolayog, 2019), and relationship between green innovation and financial performance (Xie, Huo, & Zou, 2019).

Based on many documents, the United States and China are the main contributors to green technology for business research. However, Taiwan and Australia surpass China with 2.630 and 2.477 citations, respectively, in terms of citations. Prior

studies in Taiwan have focused more on the behavioral aspects of implementing the eco-innovation strategy (Kuo & Smith, 2018; Wang, Chen, & Tan, 2019). Meanwhile, Australia's research has emphasized green information system practices in improving firms' resources (Galbreath, 2019; Walton, Zhang, & O'Kane, 2020). Furthermore, prior studies in Australia have also investigated the role of green information technology in developing business policy and strategies (Hasan & Ionescu, 2017; Townsend & Mohammadian, 2017).

In co-word analysis, there are 2.223 keywords in 735 articles that are selected. Duplicate and misspelling items are detected after selecting 2.223 keywords as basic analysis units. For instance, "green technology" and "green technologies" are merged and renamed "green technology". After that, they are filtered by their frequencies, and the keywords with less than 8 frequencies are removed. After the elimination, there are 25 high-frequency keywords used as the data in the research. The top 5 high-frequency keywords are presented in Table 3, where "eco-innovation" comes in the first rank and "sustainability" is second with 92 and 69 frequencies, respectively.

Next, VOSviewer creates the co-occurrence networks, which present connections among the 25 high-frequency keywords. Figure 5 visualizes the social network analysis that a node represents each network member. The size of the node represents the occurrence frequency. The bigger the node's size is, the higher the frequency of the occurrence is. It can be seen that "eco-innovation" has the biggest node and is followed by "sustainability".

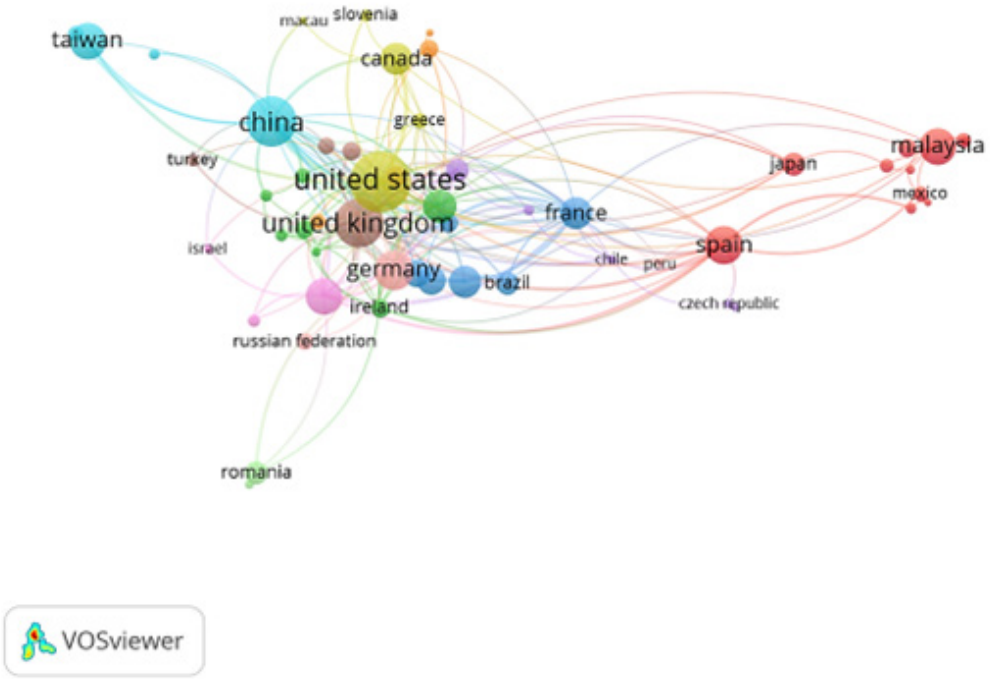

Figure 4 Network Visualization of Co-Authorship Analysis by Countries

Table 2 Countries Analysis of Green Technology for Business Research

Country	Document	Rank	Citation
United States	107	1	3.167
China	76	2	2.077
United Kingdom	72	3	1.503
Germany	48	4	1.216
Spain	42	5	1.054
Malaysia	41	6	896
Italy	40	7	709
Taiwan	40	7	2.630
Australia	33	8	2.477
India	32	9	310
France	31	10	657

Table 3 Top Five High-Frequency Keywords Related to Green Technology for Business Research

Keyword	Frequency
eco-innovation	92
sustainability	69
green it	56
green innovation	53
green technology	35

Furthermore, VOSviewer divides the 25 high-frequency keywords into four clusters, as shown in Table 4. Four parameters are applied to define the clusters (Waltman, Van Eck, & Noyons, 2010). The first parameter is clustering resolution, defined as a resolution parameter to determine the specific level of the clustering details. The second is the normalization method, which performs LinLog/modularity normalization. The next one is the minimum cluster size. The minimum number of items within each cluster is 1. The last one is the maximum number of iterations. The maximum number of iterations performed by VOSviewer software is 10.

The description of the current state of green technology for business research is based on the four clusters, as seen in Table 4. Cluster 1 is environmental performance. Green technology is one of the practices that will enhance a company's competitive advantage and economic and environmental performance (El-kassar & Kumar, 2019; Forés, 2019). It is found that green product innovation has a significant impact on business sustainability dimensions (financial,

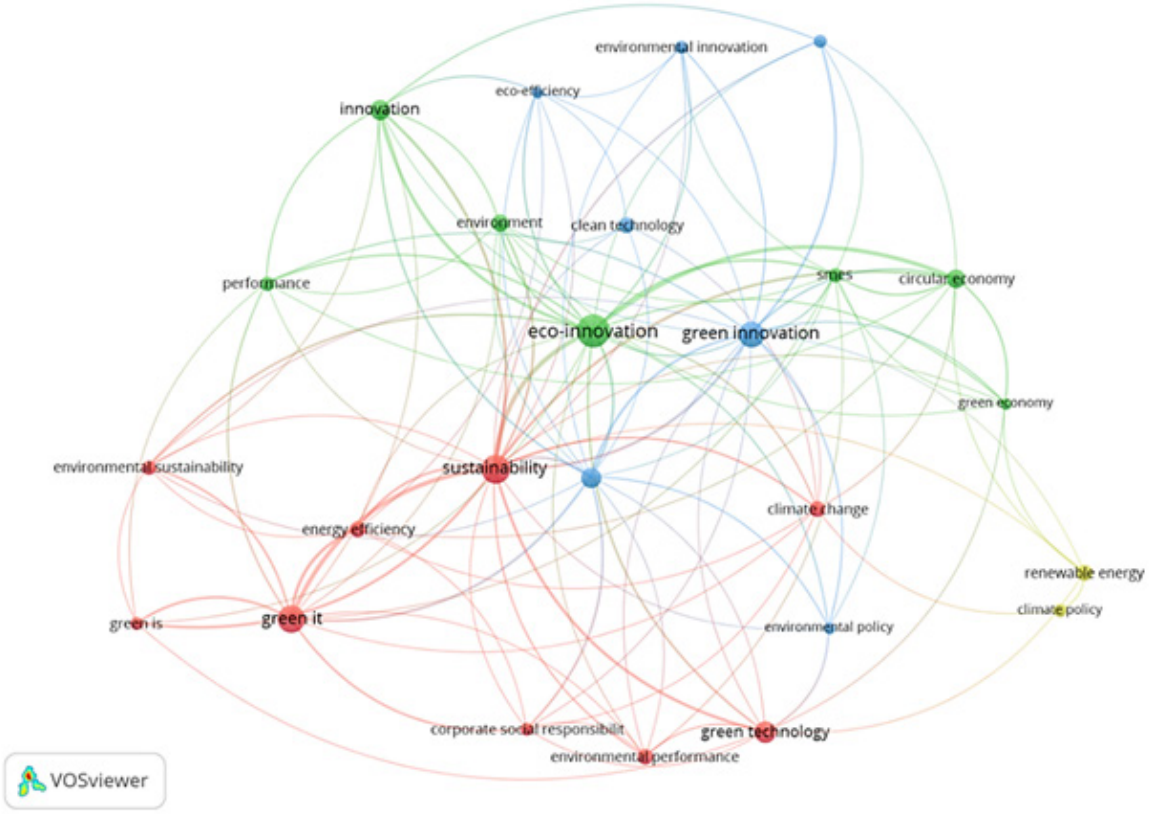

Figure 5 Network Visualization of Co-Word Analysis

Table 4 Cluster of Green Technology in Business

No	Number of Keywords	Selected Keyword	Issue
1.	9	climate change; corporate social responsibility; energy efficiency; environmental performance; environmental sustainability; green is; green it; sustainability	Environmental performance
2.	7	circular economy; eco-innovation; environment; green economy; innovation; performance; Small Medium Enterprises (SMEs)	Circular economy
3.	7	clean technology; eco-efficiency; environmental innovation; environmental management; environmental policy; green innovation; sustainable development	Sustainable development
4.	2	climate policy; renewable energy	Climate policy

environmental, and social performance) (Li et al., 2020). Furthermore, green innovation practices play mediating role in the relationship between environmental leadership and firm performance (financial and environmental performance) (Su et al., 2020). On top of that, the environmental performance of industrial companies in Brazilia is positively affected by cleaner production practices (De Oliveira et al., 2019). Therefore, it suggests the need for investment in green technology to improve environmental performance in the organizations.

Cluster 2 is the circular economy. The success of circular economy business opportunities depends on companies' engagement in implementing green innovation or eco-innovation within firms (Han, Heshmati, & Rashidghalam, 2020; Maranesi & De Giovanni, 2020; Scarpellini et al., 2020). Firms need to adopt eco-innovation to promote cleaner production methods and change consumer behavior toward a circular economy (Durán-Romero et al., 2020). In addition, there is an experiment about copper demand and supply by using four scenarios and a combination of material flow analysis, regression analysis, and life cycle assessment to predict the possibilities of reducing GHG emissions under material circularity conditions. It shows that green energy technologies can support the efforts to achieve a circular economy (Ciacci et al., 2020).

Cluster 3 is sustainable development. Environmental innovation is essential to achieve sustainable development (Ben Amara & Chen, 2020; García-Granero, Piedra-Muñoz, & Galdeano-Gómez, 2020; Walton et al., 2020). Businesses and organizations can achieve sustainable development goals when using creative approaches as part of engagement in green innovation practices (Awan, Sroufe, & Kraslawski, 2019). Furthermore, the relationship between eco-innovation strategy, environmental policies from the government, and firms' sustainable development is examined. The eco-innovation significantly mediates the relationship between governmental environmental policies and firms' sustainable business development (Ben Amara & Chen, 2020).

Cluster 4 is climate policy. Climate or environmental policy is one of the drivers that make companies adopt green technology in their business (Marin & Zanfei, 2019; Wang et al., 2019). For instance, Swedish environmental policy can promote the deployment of green technologies in polluting industries to reduce emissions while being economically effective (Weiss & Anisimova, 2019). Furthermore, there are two statements regarding bottom-up approaches to climate policy. One of them is that the development and application of green technology must be encouraged to reduce future emissions (Heal & Kunreuther, 2017). In addition, it is suggested that the effectiveness of unilateral climate policy should be complemented by the international transfer of clean technologies (Sanna-Randaccio, Sestini, & Tarola, 2017).

Lastly, co-citation analysis is the condition when two papers are cited simultaneously by a third paper (Hota et al., 2020). This section describes the references in co-citation analysis and the journals in co-citation. The reference in co-citation analysis is essential because it can identify the structure and development path of a certain domain (Liao et al., 2018). Figure 6 illustrates the co-citation patterns of the papers that are cited at least ten times. The most co-cited papers that are related to green technology in business are an article from Hart (1995) entitled "A Natural-Resource-Based View of the Firm" and Pujari (2006) entitled "Eco-Innovation and New Product Development: Understanding the Influences on Market Performance". Table 5 describes the top five most co-cited references related to green technology in business research.

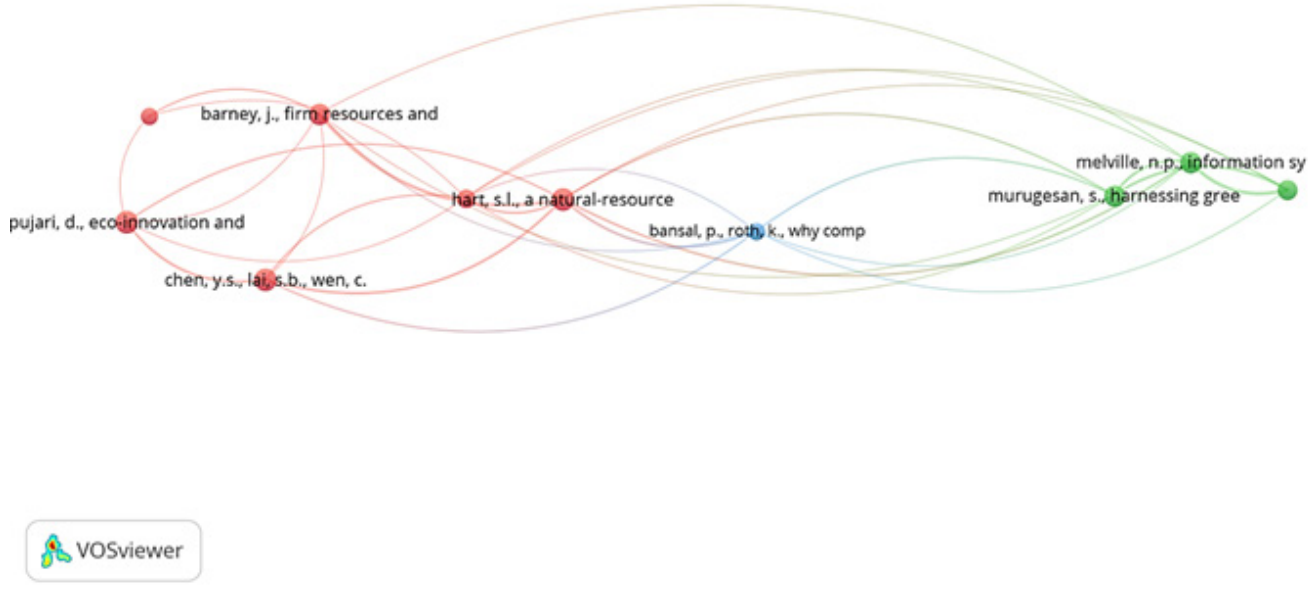

Figure 6 Network Visualization of Reference in Co-Citation Analysis

Table 5 The Top Five Most Co-Cited Documents Related to Green Technology in Business Research

Author	Citation
Hart (1995)	17
Pujari (2006)	17
Chen et al. (2006)	16
Murugesan (2008)	15
Melville and Ross (2010)	14

The next type of co-citation analysis is the journal or source co-citation analysis. This analysis is used to detect the structure and the characteristics of a subject (Liao et al., 2018). Figure 7 shows the visualization network of this analysis with 884 nodes, with Journal of Cleaner Production as the biggest node.

Table 6 shows the Top five most co-cited sources or journals related to green technology in business research. It can be seen that the most cited publication for this research topic is in Journal of Cleaner Production. It has more than 1.000 citations. Then, it is followed by Research Policy, Energy Policy, Ecological Economics, and Journal of Business Ethics, with less than 500 citations.

Based on the bibliometric analysis result and discussion, several recommendations are proposed for future research. The research identifies that green technology is mainly located in developed countries for business research. Therefore, further research on the implementation of green technology in business should be conducted in developing countries to gain a better insight.

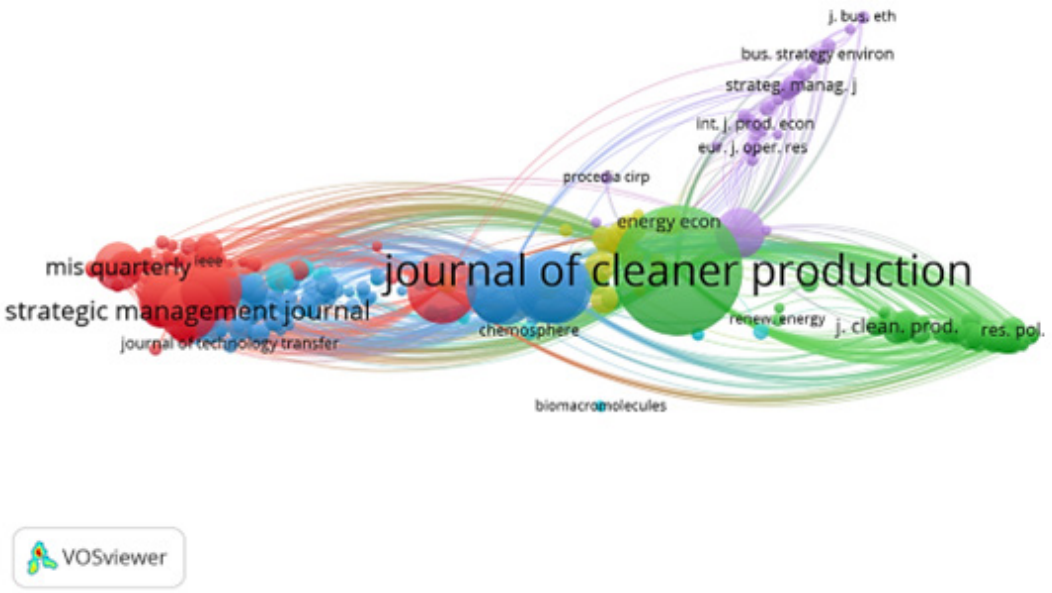

Figure 7 Network Visualization of Source Co-Citation Analysis

Table 6 The Top Five Most Co-Cited Sources of Green Technology in Business Research

Rank	Source	Citation	Subject
1	Journal of Cleaner Production	1.467	Business, Management and Accounting; Energy; Engineering; Environmental Science
2	Research Policy	492	Business, Management and Accounting; Decision Sciences; Engineering
3	Energy Policy	465	Energy; Environmental Science, Management, and Monitoring; Policy and Law
4	Ecological Economics	454	Economics, Econometrics, and Finance; Environmental Science
5	Journal of Business Ethics	422	Arts and Humanities; Business, Management, and Accounting; Economics, Econometrics, and Finance; Social Sciences

Then, most of the prior research examines the drivers or motivations that make the organizations apply or invest in green technology, such as climate policy, environmental performance, and sustainable development goals. However, only a few research integrates behavioral factors with the implementation of green technology in companies. So, future research can consider how behavioral factors, such as green culture, green behavior, green management, or organizational characteristics, can affect the use of green technology within organizations.

Furthermore, the following research can explore the methods in reviewing the environmental impact of a green technology that is applied in a company. For instance, Life Cycle Assessment (LCA) is one of the methods that is applied in evaluating the environmental impact related to the adopted green technology (Cusenza, Bobba, Ardente, Cellura, & Di Persio, 2019; Landi, Consolini, Germani, & Favi, 2019). An integrated method can also be explored to complement or improve LCA, such as introducing environmental management accounting system into LCA applications. While LCA only measures the environmental effect, the environmental management accounting system will analyze two types of data: physical information and financial data. The integration of LCA and environmental management accounting system will bring a more comprehensive evaluation to the internal decision making.

CONCLUSIONS

The research aims to identify the main themes on this topic using bibliometric methods, such as co-authorship analysis and co-word analysis. Bibliometric methods reveal the research domain, current status, and leading topics. Then, the research uses 735 articles from 1995 to 2020 from the Scopus database to obtain bibliographical records related to the field of green technology for business. From the results, there are several conclusions.

First, co-authorship analysis shows that Scarpellini S. is the most productive author based on the number of articles produced. However, Chen Y. S. is the author with the most citations. Moreover, based on the country analysis, the United States, China, and the United Kingdom are the major contributors to green technology for business research. Second, co-word analysis suggests 25 high-frequency keywords. These high-frequency keywords are divided into four clusters. Then, the research status for each cluster is presented to guide potential areas for further research. Third, co-citation analysis shows that scientific articles written by Hart (1995) and Pujari (2006) are the most co-cited documents related to green technology in business research. Furthermore, there are 844 journals in the network, and the Journal of Cleaner Production is the most co-cited source on this topic.

From a practical perspective, the research results will benefit managers who want to find a comprehensive understanding of how green technology can impact their business. Green technology will reduce emissions and waste and consume less energy. On top of that, it can support managers in decision-making to achieve sustainable business goals. For policy implications, the research can further guide the government in formulating regulations to promote green technology practices to mitigate the negative impact of climate change from the Information and Communication Technologies (ICTs) perspective. The rise of green technology investment or innovation within firms will create a sustainable business, which brings advantages to the business, society, and environment at the same time. Then, it will also support achieving Sustainable Development Goals (SDGs) faster.

The research limitation is the literature data used. The data are only obtained from the Scopus database collection, which probably does not capture all available literature on green technology for business research. Future research should add other credible international databases such as PubMed or Web of Science (WoS) to gain more comprehensive insights related to applying green technology in the business.

The research has several implications, not only for further research but also for practice and policy making. From the academic perspective, the research can guide future research since it provides an insight into the research trends and collaborations related to the use of green technology in the business field. Based on these bibliometric analysis results, future researchers can explore more the behavioral factors that can determine the adoption of green technology within organizations. Another area that can be explored is the methodology to measure the environmental impact of the adopted green technology, such as implementing LCA, which will bring a more comprehensive evaluation to the internal decision making. In addition, future studies should consider conducting research in developing countries to contribute to the limited research of green technology in developing countries.

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