

# Mapping the Research Trends on Technological Innovation in East Asia: A Bibliometric Analysis Using the Scopus Database for Future Research Direction (1982-2022)

Emmanuel Umoru Haruna<sup>1,2,\*</sup>, William Korankye Asiedu<sup>3</sup>, Yong Jun Baek<sup>4</sup>

<sup>1</sup>Department of Economic Development and Policies, Kobe University, Kobe, JAPAN.

<sup>2</sup>International Centre for Economic Analysis (ICEA), Wilfrid Laurier University, Waterloo, Ontario, CANADA.

<sup>3</sup>Department of Policy Analysis, Faculty of Economics, National Graduate Institute for Policy Studies, Roppongi-TOKYO, JAPAN.

<sup>4</sup>Center for Global Strategy, National Institute of Green Technology, Seoul, SOUTH KOREA.

## ABSTRACT

Technological innovation is accelerating advancements in artificial intelligence, 5G networks and biotechnology, driven by significant R&D investment and strong government support in emerging Asian countries. This study uses bibliometric analysis to conduct a critical review of technological innovation research in East Asia (China, Japan, South Korea and Taiwan), revealing its development, trends and significant issues and research tendencies. We use a sample of 3925 Scopus-indexed documents from 1982 to 2022 to explore a wide bibliometric analysis and network-clusters analysis of emerging research, as well as to examine future research directions using multiple softwares such as R-Studio, VOSviewer, Biblioshiny and BibTex. The study reveals that technological innovation in East Asia has increased rapidly since 2012, with the most influential and contributing authors being Lee N., Trung T., Lin B., Khan Z. and Murshed M. (37% of 20 most cited authors) and China and South Korea being the most contributing countries. Additionally, the Beijing Institute of Technology (China), Sungkyunkwan University (South Korea), The University of Kitakyushu (Japan) and China Medical University (Taiwan) were found to be the top institutions in regarding research productivity. While the keywords "technological development" and "environmental regulation" have been growing steadily since 2012, "Industrial technology", technology innovation capacity, "information technology" and "technology diffusion" have gained popularity over the past decade. However, we find a paucity of research in this field in Taiwan. Our results suggest that research in these areas is growing, with new approaches and directions emerging, but there are significant gaps, particularly in innovation management, technology policy and product development. This study has significant policy implications for technological innovation management critical for national innovation systems, as well as a collaborative opportunity for academia to understand future trends.

**Keywords:** Technology Innovation, Bibliometrics analysis, Network analysis, Citation and co-occurrence analysis, VOSviewer, East Asia. JEL classifications: O3, Q55, O31, O32, O33.

## Correspondence:

**Emmanuel Umoru Haruna**

Department of Economic Development and Policies, Kobe University, Kobe, JAPAN.

International Centre for Economic Analysis (ICEA), Wilfrid Laurier University, Waterloo, Ontario, CANADA.

Email: emharry22@yahoo.com

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## INTRODUCTION

Technological advances contribute to economic growth<sup>[1]</sup> and have a significant impact on industries and enterprises.<sup>[2]</sup> East Asian countries such as China, Japan and South Korea have demonstrated outstanding dynamic and innovative strength as a result of disruptive innovations in a wide range of technological areas. However, the region requires knowledge-based activities that promote innovation and commercialization of new ideas.<sup>[3]</sup> The long-term drivers of economic growth and development

may still require a transition in the national innovation systems. To this end, the interdependent world is likely to influence the national innovation system in no distance time. Asia, particularly East Asia, has emerged as a hotbed of innovation activities, yet disparities in economic transformation and development, as well as national innovation systems, persist. This particular pattern of innovation systems and economic transformation is visible in the industrial and service sectors. East Asia is witnessing a new frontier in technological innovation with the rise of Artificial Intelligence (AI), the Internet of Things (IoT), big data, blockchain and robotics.

However, there are not too many attempts to examine how China, South Korea and Taiwan compete with Japan and whether or not their development is reflected in the literature on national innovation systems and technological developments. Attempting



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to address these knowledge gaps in the domain of technological innovation necessitates the collection and synthesis of previous research on the subject. There have been a few studies of the literature on technological innovation that are closely related to our research. For instance,<sup>[4]</sup> assessed the level of knowledge on technological innovation in China and India from 1991 to 2015 using a bibliometric technique. Wong and Yap,<sup>[5]</sup> on the other hand, examined patent-related technological breakthroughs among international multinationals and indigenous firms in China. In addition, some of these studies seemed to have a narrow focus on knowledge management, intellectual property management, the internet of things, smart-and-sustainable cities and disruptive-innovation (Tranfield *et al.*,<sup>[6]</sup> Qiu and Lv,<sup>[7]</sup> Appio *et al.*,<sup>[8]</sup> Li *et al.*,<sup>[9]</sup> Janik *et al.*,<sup>[10]</sup> Ullah *et al.*).<sup>[11]</sup> The majority of these studies did not go into great depth regarding network and clustering analysis. As a result, future research of this literature on technological innovation using strong bibliometric methodologies and network analysis may yield new insights that were not previously understood or addressed. By concentrating on East Asia, scholars can gain insights into the state of knowledge regarding the body of literature that currently exists in the region, draw obvious similarities between the textual components they have examined and engage in discussions about the literature that is relevant to the region.

The main objective of this bibliometric analysis is to map and assess research trends in the field of technological innovations within the East Asia sub-region, specifically focusing on China, Japan, South Korea and Taiwan. The study explores the contributions published in scholarly journals, analyzing the impact across authors, institutions and regions. Further, the analysis seeks to identify areas that are attracting the most research interest to navigate future research directions. Specifically, the first question aims to explore the evolution of research work and publications in technological innovations over the period specify in our data. It identifies emerging areas of interest, patterns of research expansion and the pace of technological development in the East Asia sub-region, the second focuses on determining the most influential contributors to the field. It identifies the contributions of specific authors, institutions and journal articles that have shaped the direction and discourse of technological innovation research in the region and the final question identifies the specific areas or themes within technological innovations that have attracted the most research interest. This involves a detailed analysis of the most popular and heavily researched topics, providing insights into the dominant trends and the focal points of scholarly inquiry within the region. The paper addresses the following key research questions:

1. What are the key research growth trends in the field of technological innovation?

2. Which authors, institutions and journal articles have had the most impact on technological innovations studies over the last four decades?

3. What specific topics within the field of technological innovation have garnered the most scholarly attention and have been extensively studied?

Bibliometrics network analysis has been widely used to investigate trends in disruptive-innovation, patent-analysis and innovation-management (see, for example, Wong and Yap;<sup>[5]</sup> Chatterjee and Sahasranamam);<sup>[2,4]</sup> Bibliometric analysis identifies influential published documents and the frequency with which they are co-cited by other works on a certain topic or field. Similarly, network analysis using bibliometric approaches could be quite valuable in identifying current and developing topical areas. It can identify the research clusters and scholars by highlighting the potential for multiple views based on author and institution attributes. Identifying influential researchers within these clusters offers the groundwork for uncovering new and emerging fields of study by unearthing their most recent topics. In this study, the country-level analysis highlights a significant concentration of research on technological innovation in China and South Korea, with Japan and Taiwan contributing notably less to the field. China, in particular, leads with the majority of top publications, closely followed by South Korea. These disparities in research contributions across East Asia suggest a pressing need for enhanced regional collaboration. Policymakers are positioned to play a crucial role in promoting initiatives that encourage joint research projects and facilitate the sharing of knowledge between countries. By establishing regional innovation hubs and implementing funding mechanisms that support cross-border collaborations, policymakers can help ensure that technological advancements are more evenly distributed throughout the region. Such measures would contribute to creating a more integrated and dynamic regional innovation ecosystem, enhancing overall innovation capacity in East Asia.

The remainder of the paper is organized as follows. Section 2 focuses on related literature on conceptualizing technological innovations. Section 3 discusses the research methodology and preliminary data analysis, while Section 4 presents the bibliometric analysis. Section 5 shows the network analysis and Section 6 concludes with some potential direction for future study and highlights the limitations of this study.

### **Related research on conceptualizing technological innovation**

Technological innovation is often interpreted as the development and implementation of novel or enhanced technologies, instruments, systems and methods that lead to substantial progress or breakthroughs in a various field. However, the interpretation differs among scholar, with some concentrating on the technological features of a product or service, while others

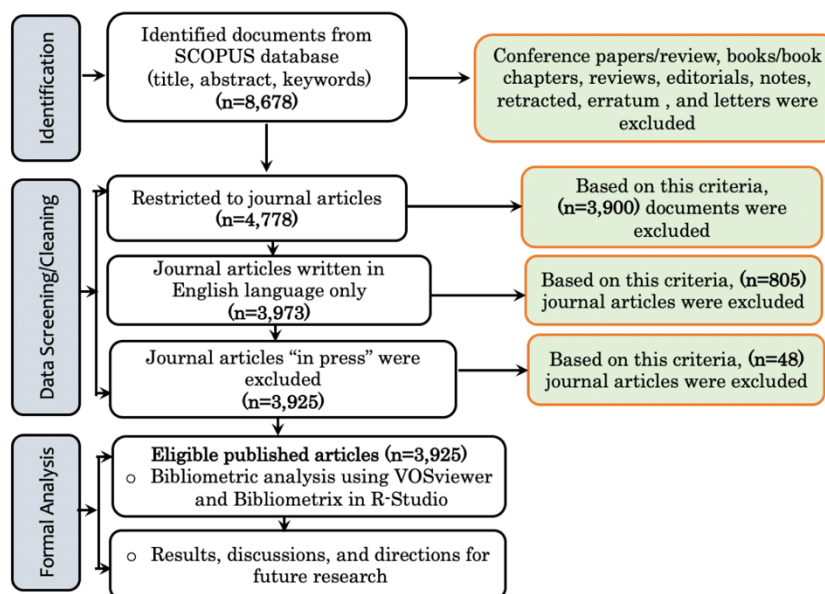
highlight the influence on the entire organization's business model. The notion of innovation draws back to Schumpeter's creative destruction, which alludes to the phenomenon where new innovations supersede old ones, rendering the old ones outdated.<sup>[12]</sup> Since then, a multitude of scholars have explored the subject of innovation and 2 notable concepts have emerged: radical innovation<sup>[13]</sup> and disruptive innovation (Christensen *et al.*;<sup>[14]</sup> Markides and Anderson).<sup>[15]</sup>

Disruptive innovation is often used interchangeably with radical innovation as both forms of innovation can potentially lead to the downfall of established companies. However, these 2 concepts are separate and pose unique challenges to firms.<sup>[16]</sup> In essence, disruptive innovation adopts a market-oriented perspective, while radical innovation concentrates on technological aspects.<sup>[17]</sup> Typically, disruptive innovation first appears in low-end or emerging markets and performs lower on dimensions that mainstream consumers find important. But when they improve their performance, they attract these customers.<sup>[18]</sup> On the other hand, technological development aimed at both mainstream and emergent markets is the basis of radical breakthroughs.<sup>[19]</sup> Radical innovation would also produce better performance than current technologies used in the mainstream market.

Bower and Christensen<sup>[20]</sup> initially suggested that disruption could stem from technology (disruptive technology), but<sup>[18]</sup> broadened the concept to encompass disruption via business models (disruptive innovation), which is referred to as the Theory of Disruptive Innovation (TDI). Since both disruptive technology and radical innovation have technological components, the term disruptive technology has evolved to disruptive innovation, adding to the ambiguity between the 2 concepts in the literature. Disruptive innovation is a business model concern and the business

model that incorporates it determines how catastrophic it is for incumbents rather than any technological features.<sup>[21]</sup> Despite the distinctions between these 2 terms, both terms are closely related under the umbrella of innovation; therefore, scholars have frequently used them interchangeably in literature.<sup>[9]</sup> This study will also adhere to the concept of TDI and will not differentiate between the 2 concepts of disruptive and radical innovation.

Research interest in disruptive innovation has steadily increased over the last ten years; in 2016, 88 articles referenced TDI,<sup>[22]</sup> and 40 papers on radical innovation were published.<sup>[23]</sup> Additionally, research on disruptive innovation in relation to emerging economies,<sup>[24]</sup> the digital economy,<sup>[25]</sup> and smart cities has expanded the field's scope.<sup>[26]</sup> Disruptive innovation is still not widely defined in study and practice, despite the field's expansion and conceptual refinements. Empirical studies of innovation at various levels, such as the national, sectoral, or firm level, have become more prevalent as technology continues to influence society. Vecchi, Della Piana and Vivacqua<sup>[27]</sup> established that China greatly outperforms India on a number of innovation criteria; this is explained by the 2 countries' different regulatory settings. Expanding upon this perspective,<sup>[4]</sup> conducted a bibliometric analysis of research on technological innovation undertaken in China and India between 1991 and 2015. Their investigation into the present level of knowledge regarding technological innovation in these 2 quickly developing economies exposed several gaps in the literature, including a dearth of studies on indigenous aspects of innovation, the management of technological innovation in India and the development of theories based on the specific circumstances of these countries. Moghaddam and Nozari<sup>[28]</sup> used the Iranian case study of subterranean natural gas storage technology to examine the dynamic evaluation of the technical



**Figure 1:** Flowchart of the bibliometric analysis on technological innovation.

Source: Authors construction based on Scopus database.

innovation system in a separate study. It's important to note that the stages of entrepreneurial activities, knowledge development and creation, knowledge distribution, system orientation, market structuring, supply and resource allocation and legitimacy are all divided into distinct parts of the technological innovation system process.

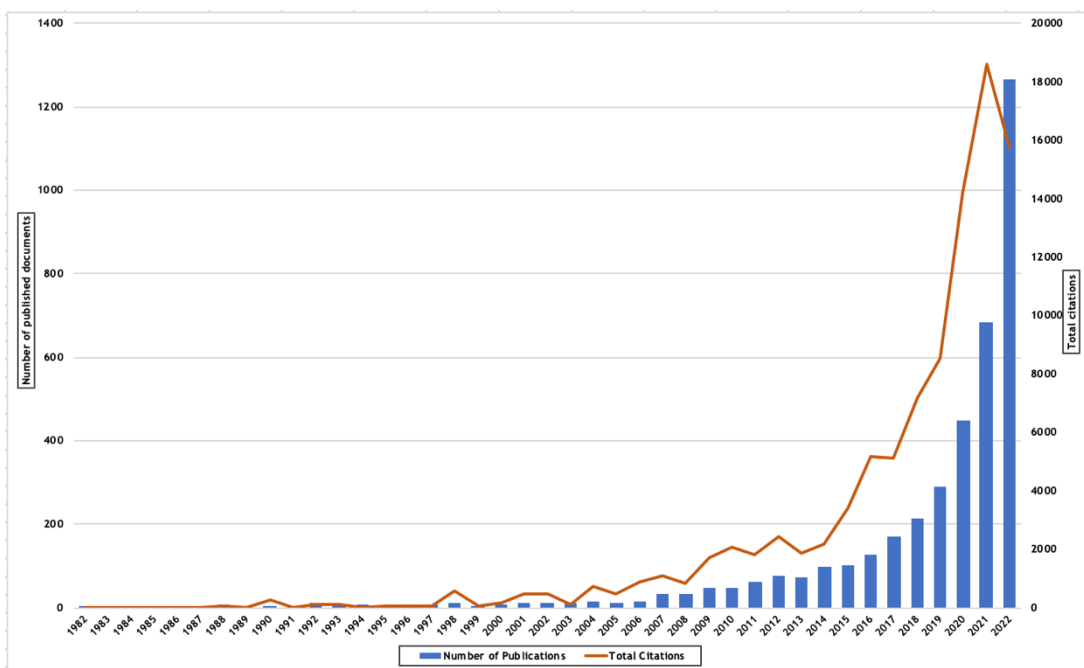
Numerous studies have redirected their attention to sector-specific investigations. Shin and Kang,<sup>[29]</sup> for instance, investigated the impact of expected interaction and cleanliness on perceived health threat and intention to reserve a hotel. This study found that lower levels of perceived health risk are associated with decreased levels of expected interaction through technology-facilitated systems. Long *et al.*<sup>[30]</sup> examined climate-smart agriculture and the primary supply-side and demand-side socioeconomic barriers impeding the uptake and diffusion of CSA technology advancements in Europe. An alternate stream of research has centered on studies at the firm level. Gnyawali and Park<sup>[31]</sup> delved into the concept of co-opetition, which involves large firms simultaneously seeking collaboration and competition. Their research indicated that co-opetition is highly advantageous for firms in tackling significant technological challenges, leading to advanced technological development. Additionally,<sup>[32]</sup> scrutinized the impact of technological innovation and sustainable management practices on the performance of Small and Medium-Sized Enterprises (SMEs), advocating for the active encouragement of Corporate Social Responsibilities (CSR) in SMEs.

The literature review shows that academic interest of innovation has been rapidly growing over time and several studies have

employed bibliometric methods to scrutinize the evolution of innovation research. Yet, to the best of our knowledge, it's challenging to locate studies that have investigated technological innovation research patterns in the four major East Asian countries. Moreover, this study has conducted a comprehensive review spanning a considerable duration from 1981 to 2022. The value of this study lies in pinpointing the lacunae in the literature, noting that while technological innovation is advancing rapidly, academic research in areas like innovation management, technology policy and product development is lagging behind.

### Research approach and preliminary data statistics

This study's bibliometric analysis differs from traditional review studies such as literature reviews and scoping reviews. According to Tranfield *et al.*,<sup>[6]</sup> the former aims to map and assess the extant literature in order to identify the potential gaps in research and highlight knowledge boundaries, while the latter uses an organized and iterative process to find and combine an established or developing body of literature on a particular topic.<sup>[33]</sup> The approaches suggested by<sup>[34]</sup> include resource scanning, creating a mind map to organize the literature review, conducting research, writing the study and creating a bibliography. The five-step data gathering and comprehensive review process described by the authors is employed in this study to determine the most influential studies, identify relevant scholarly areas and offer suggestions for future research in the field as well as insights into ongoing studies. Our bibliometric analysis was conducted using the flowchart shown in Figure 1.



**Figure 2:** Combination analysis of annual publication trends in the area of technological innovation.

Source: Authors construction based on Scopus database.

**Table 1: The preliminary search components.**

Database used	Scopus search
Keyword used	"technology," OR "innovation," and combined the 2 keywords together and "technological innovation" along with the four country names ("China", "Japan", "South Korea", "Taiwan").
Period scope	1982-2022
Total documents generated	8,678

**Table 2: Refinement of search results.**

Keyword search	Search results (Number of documents)
"technology," OR "innovation," and combined the 2 keywords together and "technological innovation" along with the four country names ("China", "Japan", "South Korea", "Taiwan").	8,678
After excluding/inclusion criteria (Total).	3,925

Note: Details of exclusion/inclusion criteria is specified in Figure 1.

### Specifying the appropriate search terms

On the Scopus database, we collected data using keywords such as "technology," OR "innovation," and combined the 2 keywords together and "technological innovation" along with the four country names ("China", "Japan", "South Korea", "Taiwan") in their author-supplied keywords. The world's biggest abstract and citation repository of peer-reviewed academic literature, Scopus, was used to gather the sample. After applying strict and systematic inclusion and exclusion criteria (see Figure 1), data cleaning, formatting and analysis were conducted using "VOSviewer" and "R-studio" (see, Aria and Cuccurullo).<sup>[35]</sup> Good statistical tools for performing bibliometric analysis include the VOSviewer software and the bibliometric packages available in R-studio. These tools help retrieve bibliometric data on influential authors, keywords, citations and productivity in top countries.<sup>[36]</sup>

### Preliminary search results

We collected and saved "journal" published articles for the specified search criteria (excluding technical papers, conference proceedings and papers, books, brief notes and book chapters). Journal articles published in English, peer-reviewed and significantly contributing to research in the domain of green finance were the inclusion criteria. The titles and abstracts of identified journal articles were extensively checked for information potentially relevant to the objective. The search results contained all of the key article information, including

the abstract, keywords, references, article title, authors names and affiliations and file formats (both "CSV" and "BibTex"). In the process, 8,678 published documents were found during the initial search. The documents collected were published from 1982 to 2022. Table 1 displays the search parameters together with the time frame.

### Refinement of the search results

As search filters or search strings, we employ access type, year of publication, author name, subject area, document type, source title, keyword, authors' affiliation, funding sponsor, country/territory, source type and language<sup>1</sup>. Duplicate journal articles were eliminated, as were short non-refereed papers, conference proceedings and papers and magazine documentaries that may not be considered scholarly contributions. In addition, recent journal publications published in 2023 were excluded due to lack of citations and influence. As shown in Table 2, a further search refinement was conducted. The bibliometric package in "R-Studio" software was used to import "CSV" file format for further analysis was done using "Biblioshiny" tool in R-studio.

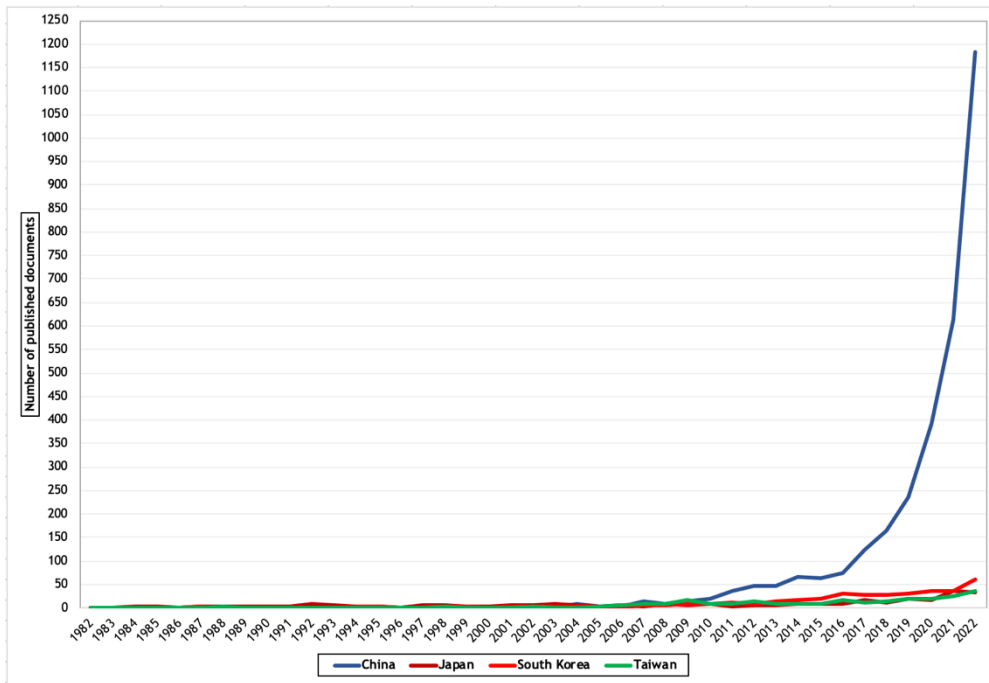
### Preliminary data statistics

#### *Publication trends in the area of technological innovation in East Asia*

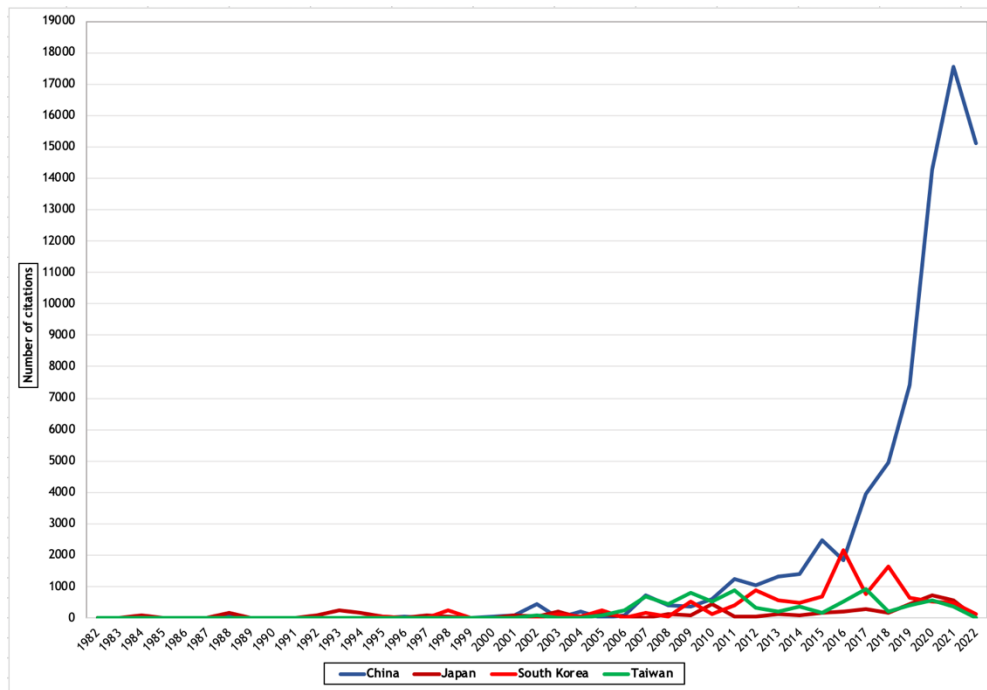
Figure 2 shows the annual publishing trends and citations of technological innovations-related published articles over a 40-year period (1982 to 2022). This analysis documented 3,925 published articles and a total of 96,725 citations. The trends indicate that publication started in 1982 with fewer citations, but the growth rate accelerated substantially from 2007 onwards and almost doubled in 2022 (with citations 15,734). This implies that, despite the fact that research on technological innovations is in its early stages, scholars and organizations are expressing interest in this field. This is attributed to huge R&D spending, rapid adoption of Intellectual Property (IP) and patent rights associated with improved productivity.<sup>[37]</sup> In Figure 2, we can see that research in the field of technological innovations has recently increased, suggesting that researchers and practitioners recognize the importance of artificial intelligence, robotics, computing power and big data in providing firms with new tools and methods for designing, producing and selling goods and services.<sup>[38]</sup>

Figure 3 was further split into country-level analysis, as shown in Figure 4. China (colored in dark blue) is steadily increasing, with annual publication of 15 research papers in 2010 increasing to 1,183 in 2022. This trend differs with South Korea (colored in red), Japan (colored in light brown) and Taiwan (colored in green), where the number of publications remained stable with 11 to 60 published articles between 2017 and 2022. South Korea came second with annual publication of 13 research papers in 2013 increasing to 60 in 2022. This suggests that in the last

1 (Scopus link)



**Figure 3:** Country-level analysis of annual publication trends in the area of technological innovation.



**Figure 4:** Country-level analysis of citations trends in the area of technological innovation.

2 decades, China's publication performance has surpassed that of the other sampled countries. A possible explanation for this could be that researchers and institutions in China may have more access to research grants than those in other countries. Yu *et al.*<sup>[39]</sup> find that collaboration with top universities guarantees access to public research funds in their recent studies on 622 Chinese universities from 2010 to 2017. Furthermore, the trend in the number of citations shown in Figure 5 is directly related

to the rate at which research articles are published each year. It is understandable that newly published research papers will obtain less citations; for example, the graph shows a decline in citation rate between 2020 and 2022.

### Data analysis

Inspired by the study conducted by<sup>[40]</sup> on bibliometric analysis and network analysis, which are given in sections 4 and 5, respectively,

we separated our statistical analysis into 2 sections. It is important to note that bibliometric analysis of the body of existing literature is carried out using a variety of software tools. These includes: Gephi, Leximancer, VOSviewer, the Biblioshiny tool in R-Studio, CiteSpace and SciVal software, among others, have proved extremely useful in recent bibliometric research (Aria and Cuccurullo;<sup>[35]</sup> Donthu *et al.*).<sup>[41]</sup> In this paper, we rely on 2 types of software: the "R package v4.3.1" and the "VOSviewer v1.6.19." With features for network research and visualization that are easy to use, each software is adaptable and convenient. The most essential software for performing a bibliometric study is the bibliometric package R, which includes the tools VOSviewer 1.6.19 and Biblioshiny 2.0. (Halepoto *et al.*;<sup>[42]</sup> Gyimah *et al.*).<sup>[43]</sup> Moreover, Web of Science and Scopus data can be combined with the program to create a single unified research work.<sup>[11]</sup> In particular, we statistically analyzed the author's influence, affiliation and keyword usage using the aforementioned software. In addition to this, plot and overlay visualization, co-citation, co-authorship and co-occurrence analysis are explored to better understand the worldwide trend of research in technological innovations. This study shed light on effective methods to generate high-quality bibliometric maps of published literature in the field investigated.

## BIBLIOMETRIC ANALYSIS

As previously stated, numerous software tools with varying functions and limits are employed for bibliometric analysis. Aside from the software already listed, well-known tools used in the existing literature include Publish or Perish<sup>2</sup>, HistCite<sup>3</sup> and BibExcel<sup>4</sup>. In this study, we used the Biblioshiny tool in R-Studio and VOSviewer primarily for simplicity and familiarity. To the best of our knowledge, our software choice, when comparing to other tools, can visualize data with clarity. The algorithm also computes journal impact measures and provides an insightful view into trends and patterns related to research topics, as well as citations computation. Because it provides additional analytical options, we consider the bibliometric R-package to be a particularly efficient, adaptable and flexible tool for bibliometric analysis.<sup>[35]</sup> Furthermore, unlike previous bibliometric mapping software tools, VOSviewer supports graphical representation and presents large bibliometric maps in an easy-to-understand format.<sup>[47]</sup> It also assists in the creation of useful visualizations revealing researcher connections and trends in research topics, as well as the relationship of significant authors' publications within a certain field.<sup>[48]</sup> Therefore, in our bibliometric study, we mix both tools, giving priority to authors, title, journal, year of publication, keywords, author affiliations and citation analysis.

**Table 3: Top 20 contributing authors: number of published documents and citations.**

Ranks	Authors	TP	TC
1	Lin, B.	20	1731
2	Li, Y.	14	444
3	Khan, Z.	12	1608
4	Kirik kaleli, D.	12	1197
5	Liu, W.	12	264
6	Murshed, M.	12	1274
7	Shahbaz, M.	11	1265
8	Yang, X.	11	694
9	Dong, K.	10	934
10	Jahanger, A.	10	777
11	Ran, Q.	10	466
12	Shao, S.	10	964
13	Zhang, J.	10	231
14	Adebayo, T.S.	9	560
15	Chen, J.	9	306
16	Chen, W.	9	435
17	Li, L.	9	654
18	Ren, S.	9	868
19	Umar, M.	9	1015
20	Wang, Ke-L.	9	344

Note: TP (Total number of published documents) and TC (Total number of citations).Source: Authors' calculation.

**Table 4: The top five country-level contributing organizations, with their location, published documents and citations.**

Institutions	Country	TP	TC
Panel A: China			
School of Management and Economics, Beijing Institute of Technology, Beijing	China	34	1820
School of Economics and Management, Harbin Engineering University, Harbin	China	19	153
College of Economics and Management, Nanjing University of Aeronautics and astronautics, Nanjing	China	18	688
Center for Energy and Environmental Policy Research, Beijing Institute of Technology, Beijing	China	16	1059
School of Economics, Ocean University of China, Qingdao	China	15	496
Panel B: South Korea			
School of Advanced Materials Science and Engineering, Sungkyunkwan University, Suwon	South Korea	2	1856
School of International Economics and Business, Yeungnam University	South Korea	2	387
Department of Electronics Engineering, 5g/Unmanned Vehicle Research Center, Hanyang University, Seoul	South Korea	1	810
Department of International Trade, Inha University, Incheon	South Korea	1	267
Department of Public Administration andong National University andong-si	South Korea	1	257
Panel C: Japan			
Faculty of Environmental Engineering, The University of Kitakyushu, Kitakyushu	Japan	3	423
Graduate School for International Development and Cooperation, Hiroshima University	Japan	2	137
School of Global Studies, Tokai University	Japan	2	105
Faculty of Agriculture, Iwate University, Morioka	Japan	1	357
Fisheries Research and Education Agency of Japan, Yokohama	Japan	1	357
Panel D: Taiwan			
Department of Medical Research, China Medical University Hospital, China Medical University, Taichung	Taiwan	5	329
Department of Marketing Management, Shih Chien University, Kaohsiung	Taiwan	4	180
Industrial Engineering and Management Department, St. John's University, Tamsui, Taipei	Taiwan	3	103
Department of Business Administration, National Taipei University, Taipei	Taiwan	2	631
Department of Finance, Asia University	Taiwan	2	307

Note: Panel A (China), Panel B (South Korea), Panel C (Japan) and Panel D (Taiwan), TP (Total number of published documents) and TC (Total number of citations).Source: Authors' calculation.

### Author influence and productivity

Citation analysis is an essential method for scientific mapping.<sup>[8]</sup> By assessing the most important papers in a field of research, one can gain insight into its intellectual dynamism.<sup>[41]</sup> We investigated authors who had minimum one research article and five citations by doing a citation analysis of each. Table 3 presents the total number of published works and citations for the top 20 most productive authors. In terms of articles published, researchers such as *Lin*, *Li*, *Khan*, *Kirik kaleli* and *Liu* were the top 5 productive authors; nevertheless, the most influential authors are *Lin* (1731

citations), *Khan* (1608 citations), *Murshed* (1274 citations), *Shahbaz* (1265 citations) and *Kirik kaleli* (1197 citations).

Researchers such as *Lin*, *Khan*, *Murshed*, *Shahbaz* and *Kirik kaleli* were among the authors who ranked highest in terms of field relevance. *Lin*'s research, for example, is deeply rooted in the field of technological innovation and covers topics such as green-technology, urban environmental pollution,

2 See, Harzing.<sup>[44]</sup>

3 See, Garfield.<sup>[45]</sup>

4 See, Persson et al.<sup>[46]</sup>

green-economic growth, energy-environmental performance, environmental regulation, wind power innovation efficiency and collaborative technology innovations. Whereas, Li focuses on product and process-innovation in state-owned companies, techno-economic performance, firms' innovative capacities, environmental regulation and green-total factor productivity and innovative-city construction. It should be noted that ranking does not always correspond to an author's relative importance in the literature.

**Affiliation statistics**

We then ran a citation analysis of organizations (universities and other research institutions) to identify those that has far more than one research publication and had received approximately 100 citations. Table 4 shows the top five prolific author affiliations in each country, together with the total number of published documents and citations. The findings demonstrate that Chinese institutions are productive, with the "Beijing Institute of Technology" having 50 published publications and 2879 citations. "Sungkyunkwan University" in South Korea came in second, with 1856 citations. Others include "University of Kitakyushu" in Japan (423 citations) and "National Taipei University" in Taiwan (631

citations). These findings indicate that the above-mentioned organizations were more committed in the field of research than others. The countries' analyses, together with their productivity (number of articles) and influence (citations), found that China and South Korea are the main contributors to the topic.

Next, we assessed at the distribution of academic journals and total citations by country in Table 5. China contributed 77.2% with 3125 published research and 75695 citations. South Korea made up 9.34%, with 378 published journal articles and 11432 citations. Japan (7.22%) has 292 published journal articles and 5704 citations, while Taiwan (6.23%) has 252 published research and 8374 citations. This implies that China has contributed more than 75% of all technological innovation research in the field. According to production and influence, China and South Korea are the leading countries in research, followed by Japan and Taiwan. The availability of grant funding in China and South Korea may also have contributed to an increase in the number of publications and citations in these countries throughout the study period, relative to Japan and Taiwan. Other explanations could be that scholars in Japan and Taiwan have difficulty publishing research articles in English. This is because we limited our Scopus query to publications in English only.



Figure 5: Authors keywords.

Source: Authors' construction using Bibliometric R-package.

Table 5: Country-level's distribution of published documents and citations.

Country	TP	TC	TP-based contribution (%)
China	3125	75695	77.2%
South Korea	378	11432	9.34%
Japan	292	5704	7.22%
Taiwan	252	8374	6.23%

Note: TP (Total number of published documents) and TC (Total number of citations). Source: Authors' calculation.

**Table 6: Top 10 journal productivity and influence.**

Rank	Source	TP	TC	Impact factor (2023)
1	Sustainability	325	4582	3.9
2	Environmental Science and Pollution Research	139	4194	5.8 (2022)
3	Journal of Cleaner Production	137	8101	11.1
4	Technological Forecasting and Social Change	108	7451	12
5	International Journal of Environmental Research and Public Health	105	1244	4.6 (2021)
6	Frontiers in Environmental Science	86	833	4.6
7	IEEE Access	64	404	3.9 (2022)
8	Plos One	49	513	3.7
9	Energy Policy	42	3473	9
10	IEEE Transactions on Engineering Management	40	648	9

Note: TP (Total number of published documents) and TC (Total number of citations).Source: Authors' calculation.

**Table 7: Top ten keywords analysis.**

Authors' keywords	Occurrences	Total link strength	All keywords	Occurrences	Total link strength
Technological Innovation	653	940	Technological Innovation	1608	9433
China	277	450	China	1160	10597
Innovation	141	189	Innovation	1111	9524
Environmental Regulation	135	262	Economic Development	419	5230
Economic Growth	77	158	Sustainable Development	402	3934
Technology Innovation	64	101	Technological Development	402	3408
Sustainable Development	63	102	Human	258	2659
Renewable Energy	60	120	Carbon Emissions	235	3086
CO <sub>2</sub> Emissions	56	126	Economics	229	2375
Financial Development	47	108	Economic and Social Effects	222	2174

Source: Authors' calculation.

Table 6 shows the top ten journals in terms of productivity and influence, together with overall total citation and impact factor. Among these journals, "Sustainability" was the most productive, with 325 academic publications, whereas "Journal of Cleaner Production" had the most influence, with 8101 citations. Analyzing the productivity, citations and impact factor identified on the webpage of respective journals, we find that "Journal of Cleaner Production" (IF: 11.1), "Technological Forecasting and Social Change" (IF: 12), "Sustainability" (IF: 3.9), "Environmental Science and Pollution Research" (IF: 5.8) and "Energy Policy" (IF: 9) are the renowned journals in the field.

### Keyword statistics

Table 7 shows an analysis of both the author's keywords and all keywords in the dataset under study. This is essential in uncovering major trends and priority areas, as well as

providing understanding on the fields of interest and ability to draw attention among scholars.<sup>[7]</sup> To accomplish this, we set the algorithm to a threshold of at least five occurrences of a keyword and 1000 keywords are selected. The keywords with the highest overall link strength are selected by computing the total strength of co-occurrence connections with other terms. The top four authors' keywords are "environmental regulation," "technological innovation," "China," and "innovation," with 653 occurrences and 940 total link strength, 277 occurrences and 450 total link strength and 141 occurrences and 189 total link strength and 135 occurrences and 262 total link strength, respectively. The top four overall keywords are "technological innovation," "China," "innovation," and "economic development," with a total of 1608 occurrences and 9433 total link strength, 1160 occurrences and 10597 total link strength and 1111 occurrences and 9524 total link strength and 419 occurrences and 5230 total link strength, respectively. This suggests that technological innovation occurs

more frequently, yet China has the highest total connection strength.

In Figure 5, we provide a word cloud analysis where the size of each word reflects the frequency of the author's keywords. The most frequently occurring words are prominently displayed in the center due to their larger size. The cloud analysis shows that "China," "technological innovation," "innovation," and "economic development" are central themes within the study. To provide more clarity, we define the major keywords as follows: China refers to the country being a significant player in technological advancements and economic development when compared with Japan, South Korea and Taiwan. Technological innovation captures the processes by which new or improved technologies are developed and brought into widespread use. In the context of our study, it specifically relates to advancements within various industries in China, Japan, South Korea and Taiwan and their impact on economic growth. Innovation is closely related to technological innovation; however, this term is broader and includes any novel ideas, processes, or products that contribute to progress. It may include non-technological aspects, such as organizational or process innovations, that drive economic change. Economic development refers to the overall progress in an economy's wealth, quality of life and standard of living, often influenced by innovations and technological advancements.

Additionally, other keywords such as "sustainable development," "technological development," and "carbon dioxide" are also highlighted, each contributing to the broader thematic analysis within the study.

## NETWORK ANALYSIS OF PUBLICATIONS

We performed a network analysis and graphical representations of published documents in the field of technological innovation using the software VOSviewer (version 1.6.20). In bibliometric studies, VOSviewer is commonly used to determine the peculiarities of a field of study.<sup>[49]</sup> It was selected for this study due to its several built-in network analysis toolboxes, broad filtering capabilities, ability to handle a variety of data types and graphical adaptability (a straightforward and user-friendly interface). Moreover, co-authorship, co-citations, citation linkages and authors keyword co-occurrence can all be seen with the VOSviewer tool.

### Citation Analysis

Table 8 shows the top 20 cited authors from 5704 in the data sample. Lee and Trung are the most influential authors, with 1856 TC and 2 published works. The authors published a groundbreaking study on a flexible and stretchable physical sensor capable of detecting temperature, pressure and strain.

**Table 8: Ranking of most 20 cited authors.**

Rank	Authors	TC	TP
1	Lee, N-E.	1856	2
2	Trung, T.Q.	1856	2
3	Lin, B.	1731	20
4	Khan, Z.	1608	12
5	Murshed, M.	1274	12
6	Shahbaz, M.	1265	11
7	Kirikkaleli, D.	1197	12
8	Jiao, Z.	1030	6
9	Umar, M.	1015	9
10	Song, M.	1001	7
11	Shao, S.	964	10
12	Dong, K.	934	10
13	Chen, D.	907	3
14	Hong, L.	880	1
15	Luo, Y.	880	1
16	Qiu, H.	880	1
17	Song, Q.	880	1
18	Wu, J.	880	1
19	Ren, S.	868	9
20	Elijah, O.	810	1

Note: TP (Total number of published documents) and TC (Total number of citations).Source: Authors' calculation.

Lin, the third most prolific author with 1731 citations and 20 documents, made contributions to green technology innovation, green supply-chain expertise and R&D performance measures. Other prominent authors include Khan (TC: 1608), Murshed (TC: 1274), Shahbaz (TC: 1265) and Kirikkaleli (TC: 1197). This analysis indicates that Lee and Trung are the most influential authors in this field.

Table 9 ranks the ten most-cited articles. The results proved the findings presented in Table 9. It is unsurprising that Trung and Lee<sup>[50]</sup> ranked first on the list with 1506 TC, trailed by Qiu *et al.*<sup>[51]</sup> who explored the epidemiological and clinical characteristics of paediatric COVID-19 patients. Elijah *et al.*<sup>[52]</sup> ranked third with 810 citations, investigating the significance of IoT and data analytics in agriculture. Cui *et al.*<sup>[53]</sup> had 590 citations and

the authors analyzed titanium's future market prospects and industry development. Finally, Wang *et al.*<sup>[54]</sup> with 572 citations, investigated the factors influencing consumer acceptance of contactless credit cards. Taking all of this into account, Trung and Lee appeared as the most significant authors in the domain of technological innovation throughout the time period under study.

### Co-citation analysis of published articles

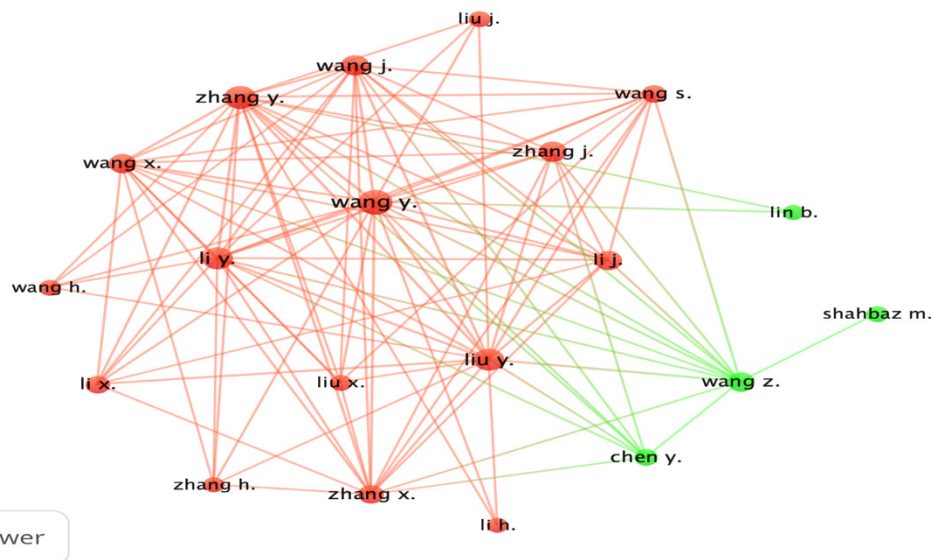
Co-citation analysis is one of the most popular approaches for analyzing a large body of literature on a certain topic. Scholars interested in counting how many times any 2 publications and authors are cited concurrently.<sup>[41]</sup> We set a 20-author threshold and a minimum of 800 citations per author. Table 10 shows the top 20 authors' ranking, TC, clusters and Total Link Strength (TLS) with some other authors using VOSviewer. Our analysis shows that Wang Y. has the most citations (1675) and TLS (142603), showing that this author's work is very influential and important in the field of technological innovation. Other prominent authors are Zhang Y. (1541 citations, 138401 TLS), Liu Y. (1442 citations, 133091 TLS), Li Y. (1395 citations, 121370 TLS) and Wang J. (1257 citations, 112344 TLS). These authors' TLS indicate that their research is frequently co-cited with other notable studies, suggesting that their study is interconnected with the field. It also means that their study findings are widely acknowledged and that they have made an important contribution to their field. Interestingly, these authors research in the same clusters, as shown in column 4.

Figure 6 clearly depicts a cluster visualization network, with each node emphasizing authors with more than 800 co-citations. The visualization centers on the nodes and clusters to which the co-cited scholars belong. In a network analysis, each node

**Table 9: Ranking of most 10 cited articles.**

Rank	Authors	TC
1	Trung and Lee <sup>[50]</sup>	1506
2	Qiu, Wu, Hong, Luo, Song and Chen <sup>[51]</sup>	880
3	Elijah, Rahman, Orikumhi, Leow and India <sup>[52]</sup>	810
4	Cui, Hu, Zhao and Liu <sup>[53]</sup>	590
5	Wang Y-M, Wang Y-S and Yang <sup>[54]</sup>	572
6	Liu and White <sup>[55]</sup>	452
7	Tsai <sup>[56]</sup>	440
8	Yam, Guan, Pun and Tang <sup>[57]</sup>	375
9	Liu and Bae <sup>[58]</sup>	371
10	Costello, Cao, Gelcich, Cisneros-Meta, Free and Froehlich <sup>[59]</sup>	357

Note: TC (Total number of citations).Source: Authors' calculation.



**Figure 6:** Network node size map of co-citation (Cluster visualization).

**Table 10: Ranking of most 20 co-cited articles.**

Rank	Authors	Citation	Cluster	Total link strength
1	Wang Y.	1675	1	142603
2	Zhang Y.	1541	1	138401
3	Liu Y.	1442	1	133091
4	Li Y.	1395	1	121370
5	Wang J.	1257	1	112344
6	Zhang J.	1221	1	101127
7	Li J.	1198	1	105530
8	Wang X.	1150	1	107274
9	Wang Z.	1134	2	100691
10	Zhang X.	1122	1	103928
11	Li X.	1041	1	91834
12	Wang S.	979	1	99063
13	Chen Y.	949	2	81998
14	Liu J.	891	1	77827
15	Liu X.	887	1	77161
16	Wang H.	871	1	77449
17	Shahbaz M.	854	2	79556
18	Zhang H.	828	1	74292
19	Li H.	818	2	72967
20	Lin B.	810	2	75268

Source: Authors' calculation.

represents a single unit of information. Authors with red nodes and color are assigned to cluster 1, whereas those green nodes and color are assigned to cluster 2. It should be noted that the algorithm ignores other nodes and clusters as we are only concerned in authors who have above 800 co-citations. The visualizations show increased link strength among authorship in clusters 1 and 2.

### Co-authorship countries network

In this part, we examine the co-authorship network among the author's affiliated countries, specifically China, South Korea, Japan and Taiwan. This approach allows us to analyze their contribution in terms of the number of documents, citations and total link strength. To do this, we set the algorithms to a minimum number of 252 documents and 800 citations per country. This parameterization ensures a threshold of equal representation across countries. Table 11 shows that China has the most international collaborations, with 3125 documents (75695 citations), followed by South Korea with 378 documents and 11432 citations. Japan has a total of 292 published articles with 5704 citations, while Taiwan has the fewest documents (252) with 8374 citations. International collaboration has significantly increased and doubled, since it represents the synergy between 2 or more experts that co-authored a paper.<sup>[60]</sup> Additionally, the number of publications in which authors worked together is

represented by the total link strength; the greater the total link strength, the stronger the link. This suggests that China has nearly doubled its total link strength in the field of technological innovation to 109 when compared to other countries. This research shows that authors from China and South Korea published the most articles and collaborated more than those from Japan and Taiwan. It also suggests that Japan and Taiwan have the potential to co-author more publications.

### Co-occurrence keywords network

This study uses the authors' keyword co-occurrence analysis to identify the important themes that emerge when conceptualizing technological innovation. Topical convergence in a research displays a homogeneous categorization of terms.<sup>[41]</sup> Table 12 presents the ranking, authors' keyword co-occurrence and TLS utilizing VOSviewer. The algorithm detected 10016 keyword occurrences among the authors. Accordingly, we selected a threshold keyword occurrence threshold of 29 and 20 keywords, respectively. Our study reveals that "Technological innovation" has the most occurrences (653), with a TLS of 235. This shows that "technological innovation" is a primary focus for many authors in the field. Followed by "China" (277 occurrence, 153 TLS), indicating that scholars in China have made considerable contributions and are influential in terms of co-authorship networking; thus, the finding is not surprising. In fact, the

**Table 11: Ranking of most 20 co-cited articles.**

Countries	Documents	Citation	cluster	Total link strength
China	3125	75695	1	109
South Korea	378	11432	1	51
Japan	292	5704	1	43
Taiwan	252	8374	1	55

Source: Authors' calculation.

**Table 12: The co-occurrence of Authors' keywords.**

Rank	Keywords	Occurrences	Total link strength
1	Technological Innovation	653	235
2	China	277	153
3	Innovation	141	52
4	Environmental Regulation	135	103
5	Economic Growth	77	63
6	Technology Innovation	64	29
7	Sustainable Development	63	36
8	Renewable Energy	60	52
9	Financial Development	47	55
10	Carbon Emissions	40	33
11	Energy Efficiency	37	30
12	Green Technological Innovation	36	24
13	Sustainability	36	16
14	Mediating Effect	35	24
15	Technological Innovations	34	16
16	Carbon Neutrality	31	18
17	Green Total Factor Productivity	30	21
18	Spatial Durbin Model	30	18
19	Spatial Spillover Effect	30	23
20	Data Envelopment Analysis	29	9

Source: Authors' calculation.

number of co-occurrences of "China" is almost one-third that of "Technological innovation." Other co-occurrence keywords include "Innovation" (141 occurrences, 52 TLS), "Environmental regulation" (135 occurrences, 103 TLS) and "Economic growth" (77 occurrences, 63 TLS).

Figure 7 provides a visual representation of author keyword co-occurrence using the biblioshiny application from our R package. The visualizations depict different nodes in a circle-shaped layout, showing a variety of keywords with high occurrence. The size of the nodes reflects the weight of every word. The proximity of the words and lines reflects the strength of their relationship. In the visualization, larger nodes signify more occurrences of a specific keyword, whereas smaller nodes indicate less occurrence. Therefore, the map shows that "Technological innovation," "China," and "Environmental regulation" appear

more frequently, indicating that they are significant to the topic under study.

### Thematic map analysis: Authors' keywords

According to Callon's centrality and density ranks, the cluster networks that the keywords belong to are presented in this subsection together with the thematic map analysis of the keywords found by the "biblioshiny" software's algorithm (see, Callon *et al.*).<sup>[61]</sup> With measurements that illustrate the weighed impact of each keyword in frequency, Figure 8 displays each keyword in a two-dimensional frame. The Y-axis shows density, a measure of a cluster network's internal strength and theme growth, while the X-axis shows network cluster centrality, which quantifies the significance of a study theme in terms of the two-dimensional frame.<sup>[36]</sup> The relevance of the topic in the sampled data, as defined by the bubble size, is assigned to each

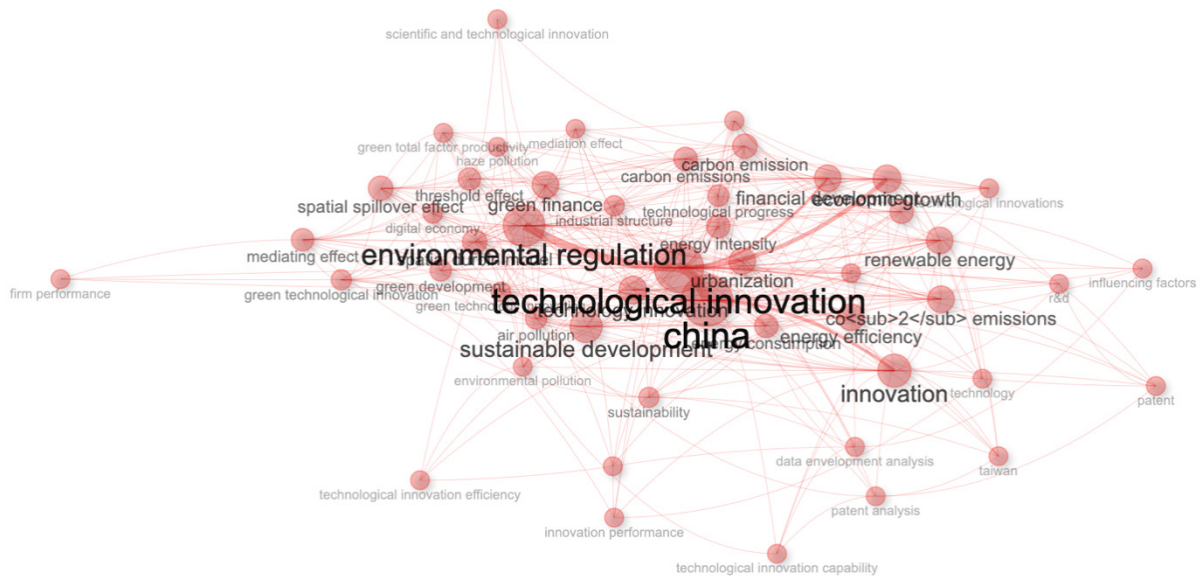


Figure 7: Co-occurrence of author's keywords.

Source: Authors' construction using Bibliometric R-package.

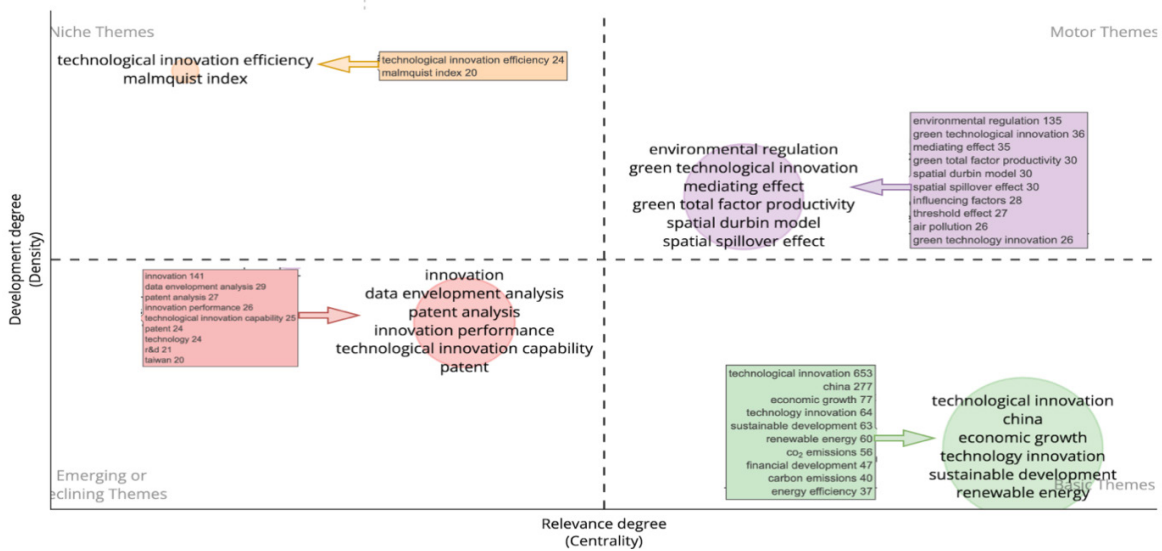


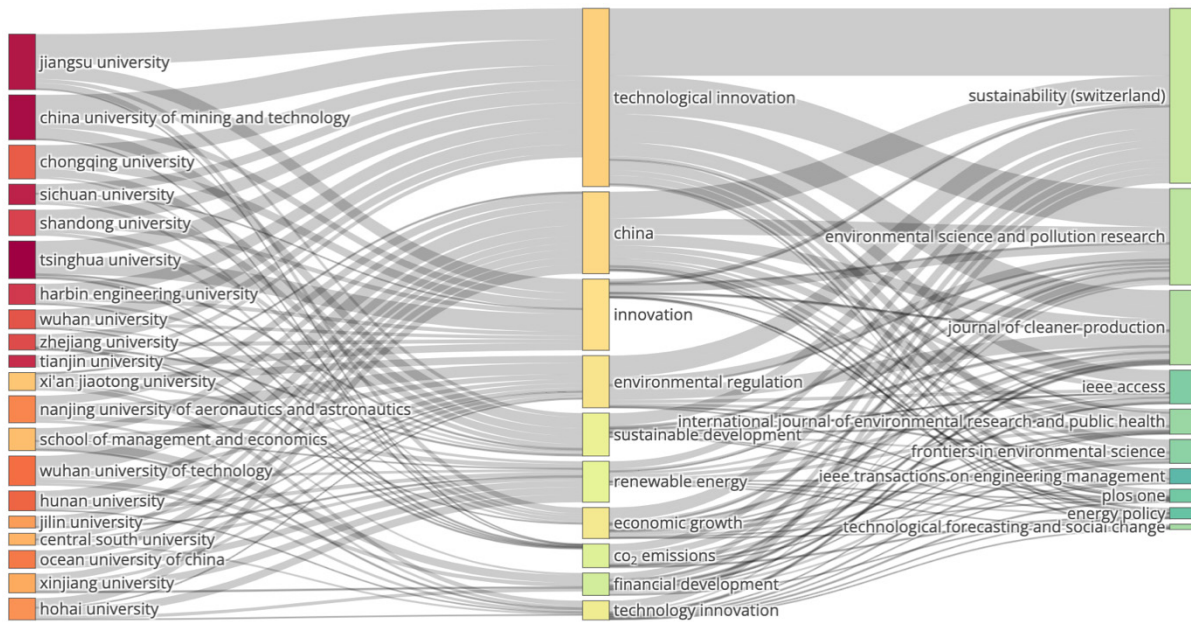
Figure 8: Thematic Analysis of authors' keyword.

Source: Authors' construction using Bibliometric R-package.

keyword in the thematic map, yielding four quadrants of keyword occurrence.<sup>[62]</sup> The centrality of authors' keywords reflects their importance in the field of technological innovation.

First, the upper left quadrant contains niche themes (technological innovation efficiency), with high density and low centrality, indicating its limited relevance; second, the upper right quadrants contain motor themes (environmental regulation, green technological innovation, mediating effect, green total factor productivity, spatial durbin model and spatial spillover effects), with low density and high centrality, implying low internal strength and themes g These are the most discussed topics in the field; third, the lower left quadrant contains the emerging or

declining theme (innovation, data envelopment analysis, patent analysis, innovation performance, technological innovation capability and patent), with high density and centrality, denoting both their high internal strength and theme growth, as well as high relevance; finally, the lower right quadrant contains the basic themes (technological Innovation). As observed on the map, the sampled data for motor themes, emerging or decreasing topics and basic themes all have the same number. These themes' graphical representation is helpful for transdisciplinary research questions since it depicts a diminishing trend on the lower left and a rising trend on the top right throughout time. In the context of technological innovation, this indicates that the topics in the lower left quadrant are new developments.



**Figure 9:** Three-Field Plot Analysis on Green Finance.

Source: Authors’ construction using Bibliometric R-package.

**Table 13: Agenda for future research.**

Cluster	Theme	Future Research Area
Cluster 1 (Green)	Technological innovation	Evaluation of numerous types of industrial and sectoral innovations connected to business performance, such as artificial intelligence, machine learning, IoT, cybersecurity, robotics/automations and blockchain.
Cluster 2 (Purple)	Environmental regulation	Investigating governance issues in environmental management, enforcement and compliance, cross-border pollution and biodiversity preservation
Cluster 3 (Pink)	Innovation	Developing new methods for open innovation, digital innovations (such as artificial intelligence and blockchain), medical technologies and interdisciplinary collaboration.
Cluster 4 (Orange)	Technological innovation efficiency	Investigating the utilization of data-driven innovation management, digital platforms, the role of application programming interfaces and supply chain management.

Source: Authors’ calculation.

### Three-field plot analysis on Technological Innovations

Inspire by the work of Janik *et al.*,<sup>[10]</sup> we analyze and visualize the Sankey diagram of the 3 fields plot, which shows the links between published articles based on 3 selected thematic fields: institutions (left); keywords (middle); and cited sources (right). Figure 9 show that Chinese institutions such as Jiangsu University, China University of Mining and Technology, Chongqing University, Sichuan University, Shandong University, Tsinghua University, Harbin Engineering University and Wuhan University completely dominated scientific research production in the field of technological innovation. These research outputs were mostly published in the journals such as Sustainability, Environmental and Pollution Research and Journal of Cleaner Production, respectively. However, we find no contributing institutions from South Korea, Japan, or Taiwan that matched this threshold of 15 sampled research organizations. We also find that the top ten keywords are Technological Innovation, China, Innovation, Environmental Regulation, Sustainable Development, Renewable Energy, Economic Growth, CO<sub>2</sub> Emissions, Financial Development and Technology Innovation. Among these research institutions, China has a high research productivity in the field of technological innovation, as well as cited sources. This study indicates Chinese institutions dominated research in the field of technological innovation. One probable explanation is that China is experiencing significant technological progress and innovation,<sup>[63]</sup> as well as major investment in green technology innovation (Yao *et al.*,<sup>[64]</sup> Woolston).<sup>[65]</sup>

## CONCLUSION

This study systematically examines the trending research on technological innovation in East Asia, with focus on China, Japan, South Korea and Taiwan from 1982 to 2022. We utilized 3925 Scopus-indexed documents to establish an extensive network and bibliometric analysis of emerging research, collaborations and author contributions in the field of technological innovations. This concerted effort documents the influence of top journals, most referenced articles, top regions and top organizations in this field of research.

The findings of this analysis suggest that the growth of research in this field emerges from 2012 to 2022, with a significant number of publications and citations throughout this time period. This stage of development featured a variety of studies using varied frameworks and methodological techniques. The most productive authors examined the field subject from several perspectives. Trung T. and Lee N. are the most influential authors, with 1856 TC and published a groundbreaking study on a flexible and stretchable physical sensor capable of detecting temperature, pressure and strain. Lin B. emerged third most prolific author with 1731 citations and 20 documents and contributed to green technology innovation, green supply-chain expertise and R&D performance measures. Other scholars such as Qiu *et al.*<sup>[51]</sup> explored the epidemiological and clinical characteristics of paediatric COVID-19 patients. Whereas, Elijah *et al.*<sup>[52]</sup> ranked third with 810 citations, investigating the significance of IoT and data analytics in agriculture. Cui *et al.*<sup>[53]</sup> had 590 citations and the authors analyzed titanium's future market prospects and industry development. Finally, Wang *et al.*,<sup>[54]</sup> with 572 citations, investigated the factors influencing consumer acceptance of contactless credit cards.

The country-level analysis highlights a significant concentration of research on technological innovation in China and South Korea, with Japan and Taiwan contributing notably less to the field. China, in particular, leads with the majority of top publications, closely followed by South Korea. These disparities in research contributions across East Asia suggest a pressing need for enhanced regional collaboration. Policymakers are positioned to play a crucial role in promoting initiatives that encourage joint research projects and facilitate the sharing of knowledge between countries. By establishing regional innovation hubs and implementing funding mechanisms that support cross-border collaborations, policymakers can help ensure that technological advancements are more evenly distributed throughout the region. Such measures would contribute to creating a more integrated and dynamic regional innovation ecosystem, enhancing overall innovation capacity in East Asia.

The growing demand for a highly skilled workforce in emerging fields such as artificial intelligence and robotics presents significant implications for education and training programs

across the region. To address these emerging needs, educational institutions must adapt their curricula and training initiatives to better prepare the next generation of workers with the skills necessary to thrive in an increasingly technology-driven economy. Anticipating and responding to these demands will be critical for maintaining the competitive edge of East Asian economies in the global market. Additionally, it is crucial to recognize the influential scholars in this field, as their work may define the trajectory of future advancements. Monitoring the publications of these key authors, along with those of their collaborators, could provide valuable insights and guidance for future research opportunities. The relatively low levels of research output from Japan and Taiwan emphasize the need for a stronger focus on technological innovations within these regions. Collaboration with established scholars and institutions from leading countries like China and South Korea will be vital in expanding the breadth of research in these areas.

Finally, the study's findings underscore the importance of themes such as "environmental regulation" and "sustainable development," suggesting that industries should prioritize innovations that align with global sustainability goals. This approach not only supports environmental stewardship but also opens up new business opportunities. The analysis points to a broader shift towards sustainability and environmental concerns within technological innovation, indicating that future research should explore how these concepts influence innovation strategies in both developed and developing regions. Understanding the evolution of these innovation concepts will be essential for shaping policies and practices that promote sustainable and inclusive growth.

## Future research direction

Consistent with the four thematic clusters identified, our analysis also suggests several possible avenues for future research that could further deepen our knowledge of technological innovation (Table 13). More research on the many forms of technical advancement that have surfaced in recent years could, in particular, build on current research areas and provide new subjects. Future study should focus on validating the numerous theoretical foundations and conceptual frameworks put forth by different sectors and industries. Lastly, further research in this field might build upon our bibliometric analysis by thoroughly examining the four clusters that we identified and taking into account the publications that we determined to be the most significant.

## LIMITATIONS

There are certain limitations to the research's scope and also the review technique that may affect further investigations. First, we only analyzed Scopus-indexed published articles from 1982 to 2022, while other newly published or in-process documents were excluded due to a lack of citations and influence. The study only

used published documents that were indexed by Scopus; results could possibly be strengthened by using additional databases, including Web of Science or Google Scholar. Second, over the course of the study period, we evaluated the most significant and relevant areas such as published documents, author citations, affiliations and countries; each of the stages that were identified might benefit from this kind of analysis. A more thorough analysis of the field might come from expanding the keywords to cover, among other things, sectoral, industrial and product innovations. This could also provide a fresh perspective on the evolution of technological innovation, as well as a new way for understanding future trends. Third, there is the possibility of performing a supplementary content analysis on specific and influential articles in order to discover gaps and research directions. Fourth, published articles in local languages were excluded from the analysis. This is attributed to published studies in sampled countries, as English is not the first spoken language. Lastly, the study focused on academic publications that have been published and relevant to the topic areas, excluding other sorts of publications from our analysis, such as short notes, book chapters, project reports, conference proceedings and related documents.

## CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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