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Exploring the Trade-Environment Linkage: A Bibliometric Investigation of Trade Openness and Carbon Emissions

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ABSTRACT

The relationship between trade openness (TO) and carbon emissions (CE) has taken center stage in environmental economics. However, the ultimate impact of TO on CE relies on the relevant scale, technique, and composition of TO. Hence, this study conducted a bibliometric analysis on 999 documents retrieved from the Scopus database, which spans from 2005 to 2024. Furthermore, this paper carried out a performance and science mapping analysis using the Excel-based tool biblioMagika, as well as OpenRefine and VOSviewer software. The study focuses on understanding the research landscape and the results indicate that there is an increasing publication trend in the TO and CE domain. The study identifies Kirikkaleli Dervis from Cyprus as the most pertinent author in this field by evaluating different metrics. Besides that, the co-occurrence analysis shows the five main clusters comprising environmental sustainability, policy modelling, climate change, regional studies, and economic growth and energy policies. Also, future research should focus on merging trade policy with climate change initiatives, examining the role of digital trade, and investigating the heterogeneous effect of TO on CE across different economic sectors and regions. Therefore, this study's findings will shed light on previous research and suggest direction for future studies.

Keywords: Trade Openness, Carbon Emissions, Bibliometric Analysis, Scopus, VOSviewer.

INTRODUCTION

The issues surrounding climate change have been some of the biggest challenges faced by humankind in the 21st century. Fundamentally, human activities are the primary driver of the

rising levels of greenhouse gases (GHGs) that led to climate change [1]. Notably, CE contributed 76% of the GHGs [2]. Hence, the Paris Agreement was introduced on 12 December 2015 at the United Nations Climate Conference (COP21) in France. The primary objective of this movement is to restrict worldwide increase in temperature to 1.5 degrees Celsius above pre-industrial levels[1]. Additionally, rapid economic expansion and the integration of a borderless economy through TO necessitate higher energy demand, which ultimately results in increased CE.

There are three primary channels through which TO can affect CE, which include the scale, technique, and composition effect [3]. Based on the scale effect, TO increases economic activity, which leads to higher energy use and consequently elevated CE. Next, the technique effect explains how TO plays a significant role in facilitating the diffusion of technology and innovation, which promotes cleaner and more energy-efficient production methods, leading to lower CE. Lastly, according to the composition effect, TO transforms the economic structure by realigning production patterns to reflect comparative advantage. Specifically, if a country specialises in carbon-intensive industries (e.g., manufacturing), it will produce higher CE. However, if the country focuses on less carbon-intensive sectors (e.g., services), it will lead to lower CE.

Ultimately, the total effect of TO on CE depends on the pertinent strength of the scale, technique, and composition effects [4]. Two possible scenarios exist: firstly, technological and/or composition effects may enable TO to reduce CE by promoting the export of clean technologies from advanced to emerging economies [5]. Secondly, TO can enhance CE through the scale effect, wherein an increase in trade activities results in elevated pollution levels[6].

[7] carried out bibliometric analysis on trade and environment with a focus on regulation, protection and policy. They recommended conducting further studies on topics related to CE. Hence, motivated by [7], this study examines the link between TO and CE through the application of bibliometric techniques. Essentially, understanding the role of TO is crucial in finding the middle ground between economic growth and environmental sustainability.

This bibliometric study seeks to investigate the following research questions through performance analysis and science mapping procedures:

1. What is the research landscape on the relationship between TO and CE?
2. What are the current publication trends that shed light on the connection between TO and CE?
3. Which authors and nations are most influential in driving the research on the relationship between TO and CE?
4. Which are the most influential articles on the topic of TO and CE?
5. What are the most frequently used keywords by authors in studies on TO and CE?
6. What are the fundamental themes in the area of TO and CE?

This paper is structured as follows: This section focuses on outlining the key research questions. Next, the second section covers the literature review. Subsequently, section three explains the data and methodology utilised for this study. As for section four, a detailed result

[1] This information is obtained from the United Nations Climate Change website at https://unfccc.int/.

and discussion are provided to tackle the pertinent research questions. Lastly, section five encompasses the conclusion and presents recommendations for future research.

LITERATURE REVIEW

Bibliometric Analysis

The term "bibliometrics" was introduced by [8] to capture the concept of adoption of mathematical and statistical techniques for books and other media. The advantages of applying bibliometric analysis include detecting emerging trends in publications, ascertaining collaboration themes, determining the research components, and analyzing the intellectual framework of a specific domain within the current literature [9]. While there is existing research on the association between TO and CE ([10], [11], [12]), to the authors' knowledge, no prior bibliometric analysis has been performed on this relationship. [7] carried out bibliometric analysis to explore the connection between TO and the environment. They specifically concentrate on environmental policy and sustainable development, utilising the Scopus database from 2000 to 2021. On the other hand, [13] performed the bibliometrics and cluster analysis on the link between international trade and sustainability, employing the Web of Science database spanning from 1990 until 2009.

TO and CE

The traditional Environmental Kuznets Curve (EKC) hypothesis, as introduced by [14], suggests an inverted U-shaped relationship between income levels and pollution. The augmented EKC extends beyond the traditional EKC framework by integrating other control explanatory variables that affect environmental quality such as trade openness [15]. Hence, the level of CE in the atmosphere attributable to TO can be elucidated by the pollution haven (hereafter abbreviated as PHV) or the pollution halo hereafter abbreviated as PHL) hypothesis. The PHV hypothesis asserts that strict environmental regulations motivate polluting companies to move their operations from developed countries to developing ones [16]. Subsequently, this action will result in higher level of CE in the host country. Conversely, the PHL suggests a condition wherein the host nation gains knowledge spillovers from TO that enhance the environmental conditions. Put differently, there is a decrease in CE for the host country [17].

Furthermore, the empirical findings on the relationship between TO and CE revealed a mixed outcome. [18] observed a positive relationship in the TO-CE nexus and validated the EKC hypothesis. They conducted this study on a total of 105 countries, dividing them into three main income groups: high-, middle-, and low-income groups. Hence, TO deteriorates the environmental quality; however, the effect differs among these distinct groups of countries. [19] suggested a similar conclusion for the European Union 5 countries, where TO has a detrimental effect on the environment. Nonetheless, the N-shaped EKC was observed. Additionally, [20] validated the inverted U-shaped EKC, demonstrating that TO negatively impacts the environment in 46 sub-Saharan African countries. In contrast, the negative relationship between TO and CE indicates the beneficial impact of TO on the environment. [21] substantiated the EKC hypothesis for 116 countries from 1990 to 2014. Specifically, for the regions of Middle East and North Africa (MENA), sub-Saharan Africa, and Asia-Pacific, it is observed that TO facilitates a better environmental quality. Furthermore, [22] also corroborated the EKC hypothesis and finds that the presence of TO inhibits environmental damages.

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DATA AND METHODOLOGY

Search Strategy

This paper used a systematic search strategy to conduct bibliometric analysis and capture the comprehensive relationship between TO and CE. We employed the Scopus database to extract the relevant documents and address the research questions. This is because the Scopus database has an extensive dataset encompassing a wide array of journals in comparison to other databases (e.g., Web of Science) [23]. Firstly, we conducted the search string (TITLE-ABS-KEY (trade AND openness) AND TITLE-ABS-KEY (carbon AND emission* OR co2 AND emission* OR co2)). Subsequently, the query yielded a total of 1073 documents. Next, we further refined the dataset through the filtering process. This includes narrowing the range of years from 2005 to 2024. Additionally, we will exclude conference reviews, errata, retracted papers, and reviews from this document type. Lastly, we only include documents that have reached the final publication stage. As a result of this exclusion process, the final dataset consists of 999 documents. Figure 1 visualizes the flowchart for the search strategy.

Data cleaning and harmonization are essential processes in bibliometric analysis to guarantee the precision and dependability of outcomes. Therefore, we employ OpenRefine and bliblioMagika [24] as our main tools to clean and harmonize disorganized data such as author names, affiliations, and keywords. We begin our analysis by downloading the Scopus data in .csv file format. Next, we employed OpenRefine to standardize data efficiency and enhance its accuracy. On the other hand, we used bliblioMagika to generate bibliometric measurements such as the total number of publications (TP), number of contributing authors (NCA), number of cited publications (NCP), total citations (TC), average citations per publication (C/CP), average citations per cited publication (C/CP), h-index (h), and g-index (g). Finally, we used the VOSviewer software to illustrate the author's keywords through co-occurrence network analysis.

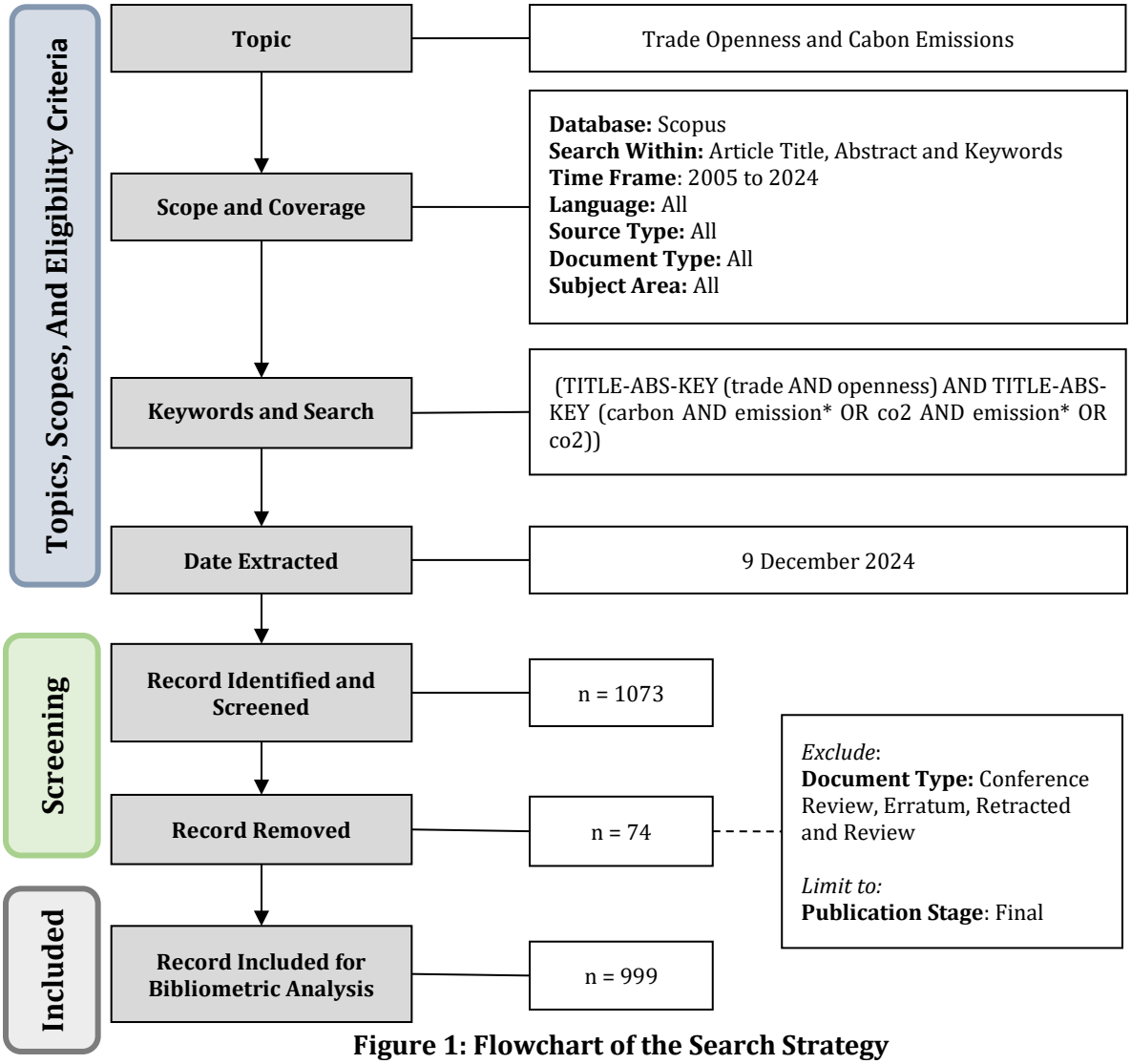

Figure 1: Flowchart of the Search Strategy
Source: [25]

RESULTS AND DISCUSSION

Research Landscape

We conducted an analysis on the metadata categories within the Scopus database to address the first research question, which aims to understand the existing landscape regarding the relationship between TO and CE. Specifically, the distinct classifications examined include document type, source type, language, and subject area. Additionally, we provide a detailed discussion of the overall citation metrics to better comprehend the impact and significance of TO and its relationship to CE.

Firstly, Table 1 shows the distribution of document type in a diverse range of formats. For example, articles, book chapters, conference papers, books, and notes. As seen in Table 1, most of the publication is in the format of an article, accounting for 96.10%, followed by book chapters comprising 1.90% and conference papers at 1.80%. On the other hand, the two least frequently published document types include books and notes, each at 0.10%.

Table 1: Document Type

Document Type	Total Publications	Percentage (%)
Article	960	96.10
Book Chapter	19	1.90
Conference Paper	18	1.80
Book	1	0.10
Note	1	0.10
Total	**999**	**100.00**

Subsequently, Table 2 highlights the distribution of publications among four sources: journal, book, conference proceeding, and book series. The predominant source type is journal, with 96.10% of the total publications. Books and conference proceedings each represent 1.40% of the total. The least common document type is book series, accounting for 1.10%.

Table 2: Source Type

Source Type	Total Publications	Percentage (%)
Journal	960	96.10
Book	14	1.40
Conference Proceeding	14	1.40
Book Series	11	1.10
Total	**999**	**100.00**

Table 3 offers a comprehensive overview of publishing distribution by language, without any specific language limits, which is essential in providing a global viewpoint. Approximately 98.70% of the documents are in English, comprising the majority of the total publications. Conversely, the remainder of the publication constitutes less than 1.00%, comprising Chinese at 0.17%, Persian and Turkish at 0.20%, and Polish and Spanish at 0.10% each. This signifies that English is the predominant language employed in analysing the relationship between TO and CE.

Table 3: Language

Language	Total Publications	Percentage (%)
English	986	98.70
Chinese	7	0.70
Persian	2	0.20
Turkish	2	0.20
Polish	1	0.10
Spanish	1	0.10
Total	**999**	**100.00**

Next, Table 4 presents the documents categorized by subject area, offering insight into the interdisciplinary characteristics of the relationship between TO and CE. According to Table 4, a significant proportion of research is categorized under the "Environmental Science" subject area at 60.96%. The subsequent categories are “Energy,” “Economics, Econometrics, and Finance,” and “Social Sciences,” comprising 29.63%, 23.52%, and 20.52%, respectively. Additionally, "Engineering" and "Business, Management, and Accounting" are documented as

12.51% and 12.01%, respectively. Finally, other subject areas constitute less than 10% of the total publications, while subject areas comprising less than 1% are not reported in the table.

Table 4: Subject Area

Subject Area	Total Publications	Percentage (%)
Environmental Science	609	60.96
Energy	296	29.63
Economics, Econometrics and Finance	235	23.52
Social Sciences	205	20.52
Engineering	125	12.51
Business, Management and Accounting	120	12.01
Computer Science	57	5.71
Mathematics	40	4.00
Earth and Planetary Sciences	39	3.90
Agricultural and Biological Sciences	28	2.80
Multidisciplinary	21	2.10
Decision Sciences	20	2.00
Medicine	17	1.70
Arts and Humanities	15	1.50
Chemical Engineering	15	1.50
Psychology	13	1.30

Note: Few documents have been classified across multiple subject areas.

Lastly, Table 5 indicates the citation metrics, which provide a concise overview of the information regarding the bibliometric dataset. Based on Table 5, the study examined a total of 999 publications, generating 60,749 citations over a 20-year period from 2005 to 2024. In particular, the average number of citations per year stands at 3197.32, the average number citations per paper at 60.81, the average number citations per cited paper at 66.90 and the average number citations per author at 18.58. Moreover, the average number of authors per paper is documented at 3.27, indicating frequent collaboration among multiple authors. Furthermore, the h-index integrates metrics of both the productivity (publication count) and influence (citation count) of a researcher [26] and stands at 127. On the other hand, the g-index addresses the weakness of the h-index by assigning more weight to highly cited publications [27], which is at 215.

Table 5: Citation Metrics

Metrics	Data
Publication Years	2005 - 2024
Total Publications	999
Citable Year	20
Total Citations	60,749
Citation per Year	3197.32
Citation per Paper	60.81
Citation per Cited Paper	66.90
Citation per Author	18.58
Authors per Paper	3.27
h-index	127
g-index	215

Publication Trends

We conduct an in-depth examination of publication trends to tackle the research question on current trends in the relationship between TO and CE. Hence, by examining these trends, we can gain meaningful insights into the growth, influence, and quality of the research output. Table 6 shows a detailed breakdown of the data based on the publication by year. Generally, there are three distinct phases observed in the evolution of the publication patterns. Firstly, we observe the initial growth phase (i.e., 2005 to 2011), which is marked by a low TP count but high C/P and C/CP rates, suggesting the presence of seminal works that garner significant citations. Secondly, a steady increase in TP and TC indicates the expansion phase (i.e., 2012 to 2019), demonstrating growing interest and diversification of the research domain. In the final stage, known as the saturation and consolidation phase (i.e., 2020 to 2024), notable surges in TP coincided with a decline in the C/P and C/CP rates. Therefore, this might indicate that there is an increase in competition and potential saturation in the research topic.

Furthermore, in line with the increase in TP, both NCA and NCP also showed an upward trend. Particularly, in 2023, it is observed that NCA and NCP peaked at 699 and 182, respectively. Although both NCA and NCP exhibited the growing scope of collaboration and the increasing exposure of researchers, it also suggests the challenge in sustaining significant influence amid the swift expansion. As for the h-index and g-index, the steady growth of the values over the years suggests the increasing significance and relevance of the relationship between TO and CE.

Table 6: Publication by Year

Year	TP	NCA	NCP	TC	C/P	C/CP	h	g
2005	1	2	1	32	32.00	32.00	1	1
2007	1	1	1	145	145.00	145.00	1	1
2009	4	7	4	935	233.75	233.75	4	4
2010	1	2	1	28	28.00	28.00	1	1
2011	4	6	4	2338	584.50	584.50	4	4
2012	4	9	3	662	165.50	220.67	3	4
2013	7	16	7	2108	301.14	301.14	6	7
2014	18	43	18	3264	181.33	181.33	15	18
2015	15	41	15	3772	251.47	251.47	14	15
2016	29	76	27	5074	174.97	187.93	20	29
2017	39	112	38	4500	115.38	118.42	26	39
2018	40	106	39	4579	114.48	117.41	27	40
2019	81	281	79	8062	99.53	102.05	47	81
2020	98	301	94	7449	76.01	79.24	53	86
2021	139	468	134	8075	58.09	60.26	53	87
2022	155	538	152	5290	34.13	34.80	40	66
2023	195	699	182	3314	16.99	18.21	28	48
2024	168	562	109	1122	6.68	10.29	16	30
Total	**999**	**3270**	**908**	**60749**	**60.81**	**66.90**	**127**	**215**

Note: TP = total number of publications; NCA = number of contributing authors; NCP = number of cited publications; TC = total citations; C/P = average citations per publication; C/CP = average citations per cited publication; h = h-index, and g = g-index.

In addition, Figure 2 illustrates the trend of total publications and citations by year, covering the period from 2005 to 2024. The bar chart depicts the surge in the total number of

publications, especially post-2016. The total number of publications rose rapidly from 2017 and steadily peaked in 2023 with 195. However, the shift in research themes within the environmental economics domain may have caused a slight decline in 2024. As a result, there is a comparatively lower number of publications in this specific field. On the other hand, the line graph illustrates a rising number of citations, signifying an expanding influence in this study domain.

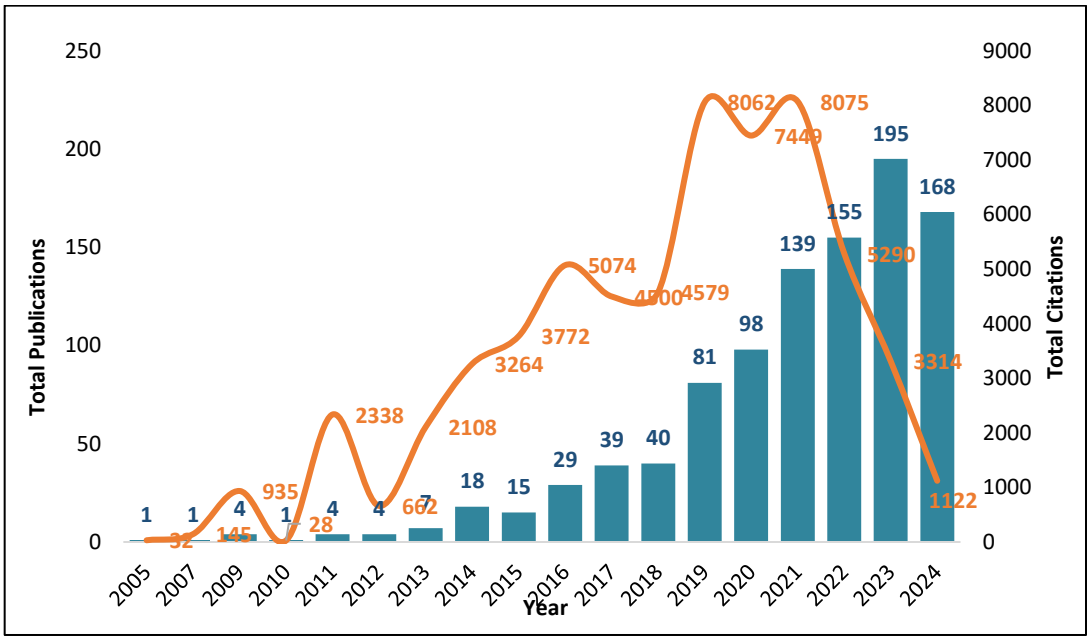

Figure 2: Total Publications and Citation by Year

Publication by Authors and Countries

In this section, we address the research question by identifying the key authors and countries driving the research on the relationship between TO and CE. First and foremost, we analyse the most productive authors, highlighting only those who have produced more than ten publications (Table 7). Table 7 reveals that Kirikkaleli Dervis from the European University of Lefke in Cyprus and Zaman Khalid from the University of Haripur in Pakistan have published the highest total of 24 papers, 24 of which have received citations. Dervis's papers accumulated 1345 total citations, garnering an average of citations per paper and per cited paper at 56.04, with the h-index of 17 and g-index of 24. In terms of Khalid's papers, they gathered 1027 total citations and an average of 42.88 citations per paper and per cited paper, with the h-index of 16 and g-index of 24. The thorough analysis in Table 7 offers valuable insight into aspects such as the author's productivity, citation impact factor, and their significance fields of TO and CE.

Table 7: Most Productive Authors with More than 10 Publications

Full Name	Current Affiliation	Country	TP	NCP	TC	C/P	C/CP	h	g
Kirikkaleli, Dervis	European University of Lefke	Cyprus	24	24	1345	56.04	56.04	17	24
Zaman, Khalid	University of Haripur	Pakistan	24	24	1029	42.88	42.88	16	24
Wang, Qiang	China University of Petroleum	China	18	17	2170	120.56	127.65	15	18

Ozturk, Ilhan	University of Sharjah	United Arab Emirates	18	18	3974	220.78	220.78	14	18
Li, Rongrong	China University of Petroleum	China	15	14	1525	101.67	108.93	13	15
Adebayo, Tomiwa Sunday	Cyprus International University	Türkiye	13	13	1120	86.15	86.15	13	13
Nassani, Abdelmohsen A.	King Saud University	Saudi Arabia	13	13	384	29.54	29.54	9	13
Balsalobre-Lorente, Daniel	Azerbaijan State University of Economics	Azerbaijan	13	12	2094	161.08	174.50	11	13
Shahbaz, Muhammad	Beijing Institute of Technology	China	12	12	3786	315.50	315.50	12	12
Udeagha, Maxwell Chukwudi	University of Pretoria	South Africa	11	11	538	48.91	48.91	10	11
Abro, Muhammad Moinuddin Qazi	King Saud University	Saudi Arabia	11	11	310	28.18	28.18	8	11

Note: TP = total number of publications; NCP = number of cited publications; TC = total citations; C/P = average citations per publication; C/CP = average citations per cited publication; h = h-index, and g = g-index.

Figure 3 illustrates the map depicting the productivity of authors by country. The gradient scale at the top of the map transitions from light pink (i.e., lower total publications) to deep magenta (i.e., higher total of publications), while the country shaded in grey signifies zero publications. According to Figure 3, the two highest numbers of publications originate from the Asian continent, specifically China with 358 publications and Pakistan with 180 publications. Next, Türkiye from the European continent with 148 publications occupies the third spot.

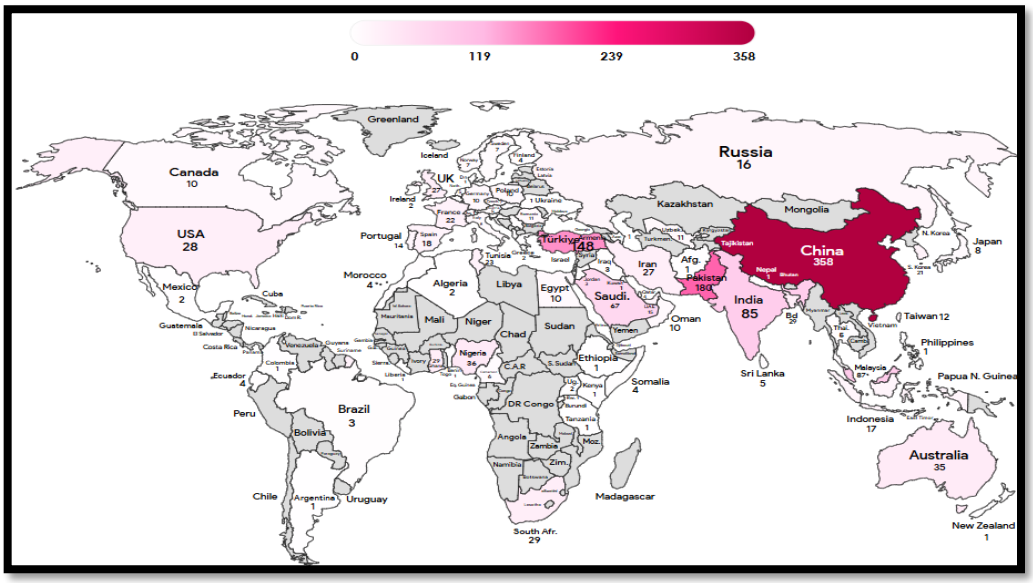

Figure 3: Map of the Productivity of Authors by Country

Highly Cited Documents

Fundamentally, the highly cited documents provide an overview of the key essential articles that played a crucial role in shaping the path of the research that investigated the relationship between TO and CE. Hence, in response to our fourth research question, Table 8 provides a list of the top 10 highly cited articles that have significantly influenced TO and the CE domain. The article by [19] published in "Energy Policy", titled "How do economic growth, renewable electricity, and natural resources contribute to CO2 emissions?" has received the highest number of citations, accumulating 1082 cites and 154.57 cites per year. This is closely followed by [28] in the second spot, published in "Economic Modelling", with the article titled "CO2 emissions, economic growth, energy consumption, trade and urbanization in new EU member and candidate countries: A panel data analysis" garnering 1010 citations and 101 cites per year. On the other hand, the article titled, "Determinants of carbon dioxide emissions: Empirical evidence from 69 countries", published in "Applied Energy" by [28], has the lowest citation count at 6209 citations and 44.93 citations per year.

Table 8: Top 10 Highly Cited Articles

Num.	Author(s)	Title	Source Title	Cites	Cites per year
1	Balsalobre-Lorente D.; Shahbaz M.; Roubaud D.; Farhani S. (2018)	How economic growth, renewable electricity and natural resources contribute to CO2 emissions?	Energy Policy	1082	154.57
2	Kasman A.; Duman Y.S. (2015)	CO2 emissions, economic growth, energy consumption, trade and urbanization in new EU member and candidate countries: A panel data analysis	Economic Modelling	1010	101.00
3	Ozturk I.; Acaravci A. (2013)	The long-run and causal analysis of energy, growth, openness and financial development on CE in Turkey	Energy Economics	980	81.67
4	Jalil A.; Feridun M. (2011)	The impact of growth, energy and financial development on the environment in China: A cointegration analysis	Energy Economics	939	67.07
5	Dogan E.; Turkekul B. (2016)	CO2 emissions, real output, energy consumption, trade, urbanization and financial development: testing the EKC hypothesis for the USA	Environmental Science and Pollution Research	884	98.22
6	Dogan E.; Seker F. (2016)	Determinants of CO2 emissions in the European Union: The role of renewable and non-renewable energy	Renewable Energy	833	92.56
7	Sharif Hossain M. (2011)	Panel estimation for CO2 emissions, energy consumption, economic	Energy Policy	738	52.71

		growth, TO and urbanization of newly industrialized countries			
8	Shahbaz M.; Kumar Tiwari A.; Nasir M. (2013)	The effects of financial development, economic growth, coal consumption and TO on CO2 emissions in South Africa	Energy Policy	671	55.92
9	Zhu H.; Duan L.; Guo Y.; Yu K. (2016)	The effects of FDI, economic growth and energy consumption on CE in ASEAN-5: Evidence from panel quantile regression	Economic Modelling	653	72.56
10	Sharma S.S. (2011)	Determinants of carbon dioxide emissions: Empirical evidence from 69 countries	Applied Energy	629	44.93

Top Keywords

The focus of this section is to investigate the research question on the most frequently used keywords by the authors. Table 9 shows the top 10 keywords used by the authors, with "Carbon Emissions" emerging as the most frequently occurring keyword, accounting for a total count of 616, representing 12.13%. This is followed by “Trade Openness”, “Economic Growth” and “Environmental Kuznets Curve” at 6.89%, 4.06%, and 3.64%, respectively. Essentially, economic growth plays an important role in the link between TO and CE. This is because TO drives economic growth, which leads to higher energy consumption and fuels higher CE in the atmosphere. Conversely, TO can also promote green growth through technological diffusion and clean energy investment, which benefits the environment. On the other hand, the environmental kuznets curve plays a crucial role as a theoretical model for the relationship between TO and CE.

Table 9: Top 10 Authors’ Keyword

Author Keywords	Count	Percentage
Carbon Emissions	616	12.31%
Trade Openness	345	6.89%
Economic Growth	203	4.06%
Environmental Kuznets Curve	182	3.64%
Renewable Energy	159	3.18%
Energy Consumption	143	2.86%
Environmental Quality	106	2.12%
Financial Development	102	2.04%
Foreign Direct Investment	101	2.02%
Urbanization	63	1.26%

Co-occurrence Analysis

We aim to resolve the final research question by pinpointing the essential themes in the domain of TO and CE. We produced the network visualization using the full counting method, also by applying a minimum of 10 occurrences per keyword to reduce the total of 1075 keywords to 70 significant ones. This filtering process is deemed crucial to ensure only frequently used keywords contribute to the visualization. Next, we carried out the co-occurrence analysis by

producing the network and overlay visualization map generated using VOSviewer software. Essentially, the co-occurrence analysis lays the foundation for identifying the crucial key patterns in the association between frequently used terms. The network visualization conveys information regarding keyword cluster groups whereas the overlay visualization indicates the average publication per year. Hence, Figure 4 illustrates the network visualization map of the co-occurrence by author keywords generated whereby keywords such as "carbon emissions", "economic growth" and "environmental kuznets curve" have larger node sizes, indicating the higher frequencies of these keywords in the dataset. Moreover, Figure 4's five colors indicate the grouping of the author keyword into five main clusters. Also, Table 10 presents the five clusters that exist in the network visualization map. Firstly, Cluster 1 in red indicates the main theme of environmental sustainability. Cluster 2 in green represents the policy modelling, whereas Cluster 3 in blue describes the climate change. Next, Cluster 4 in yellow denotes the regional studies. Lastly, Cluster 5 in purple shows economic growth and energy policies.

On the other hand, Figure 5 illustrates the overlay visualization map of the co-occurrence based on average publications per year. According to Figure 5, the color scale goes from blue (i.e., pre-year 2020) to yellow, which highlights the more recent and emerging topics. There is a clear transition from the traditional trade-emission studies (e.g., EKC and economic growth) to sustainability-driven and policy-guided studies. There is an emerging trend of studies that emphasize topics such as green finance, carbon neutrality, and green technology. Additionally, the future research should focus on merging trade policy with climate change initiatives, examining the role of digital trade, and investigating the heterogeneous effect of TO on CE across different economic sectors and regions.

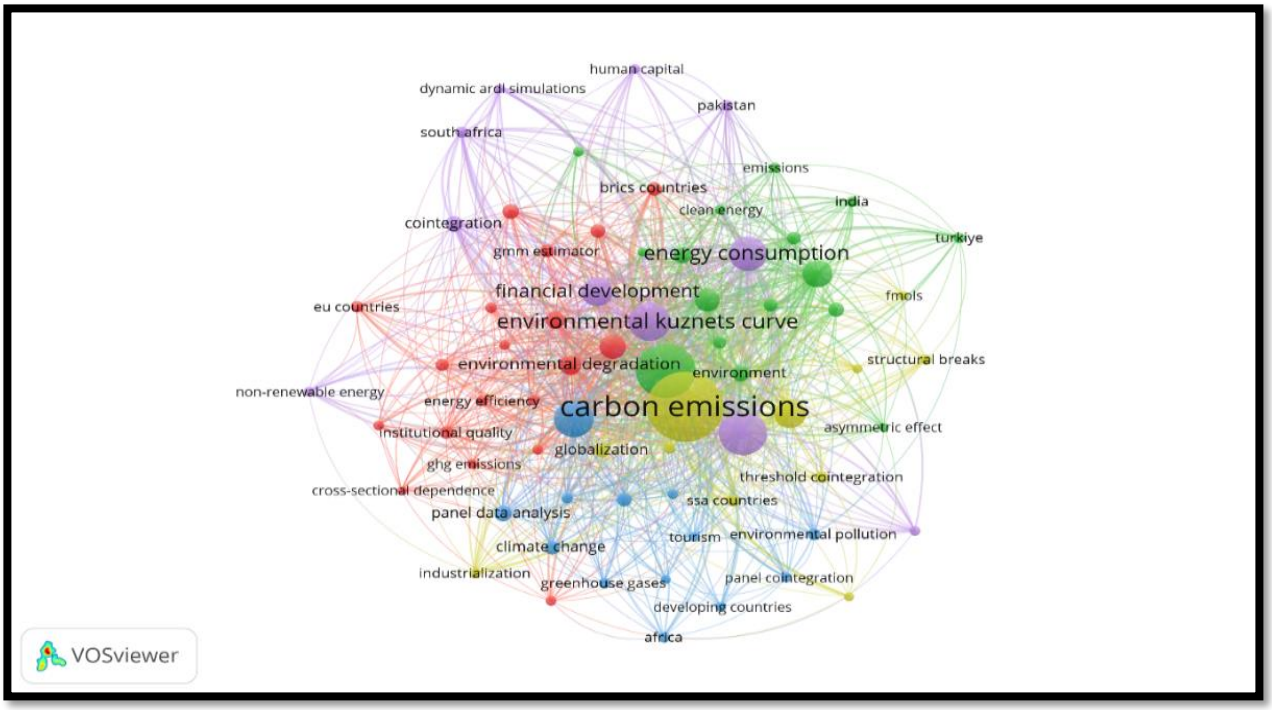

Figure 4: Network Visualization Map of The Co-Occurrence by Author Keywords using VOSviewer

Table 10: Cluster of the Co-occurrence Analysis of Author's Keywords

Cluster 1 (Red)	Cluster 2 (Green)	Cluster 3 (Blue)	Cluster 4 (Yellow)	Cluster 5 (Purple)
Environmental sustainability	Trade openness	Renewable energy	Carbon emissions	Economic growth
Environmental degradation	Ardl model	Panel data analysis	Foreign direct investment	Environmental kuznets curve
Sustainable development	Urbanization	Climate change	Globalization	Energy consumption
Technological innovation	China	Economic development	Ssa countries	Financial development
Natural resources	Environment	Environmental pollution	Threshold cointegration	Cointegration
Brics countries	Pollution haven hypothesis	Africa	Stirpat model	South africa
Gmm estimator	Energy	Causality test	Industrialization	Pakistan
Institutional quality	Nardl model	Greenhouse gases	Structural breaks	Human capital
Ecological footprint	Carbon neutrality	Tourism	Belt and road initiative	Pmg estimator
Energy efficiency	India	Developing countries	Fmols	Non-renewable energy
Eu countries	Turkiye	Innovation	Mediating effect	Dynamic ardl simulations
Green technology	Carbon emission efficiency	Panel cointegration		
South asia	Clean energy	System gmm		
Oecd countries	Emissions			
Quantile regression model	Asymmetric effect			
Ghg emissions	Income distribution			
Green finance				
Ict				
Cross-sectional dependence				

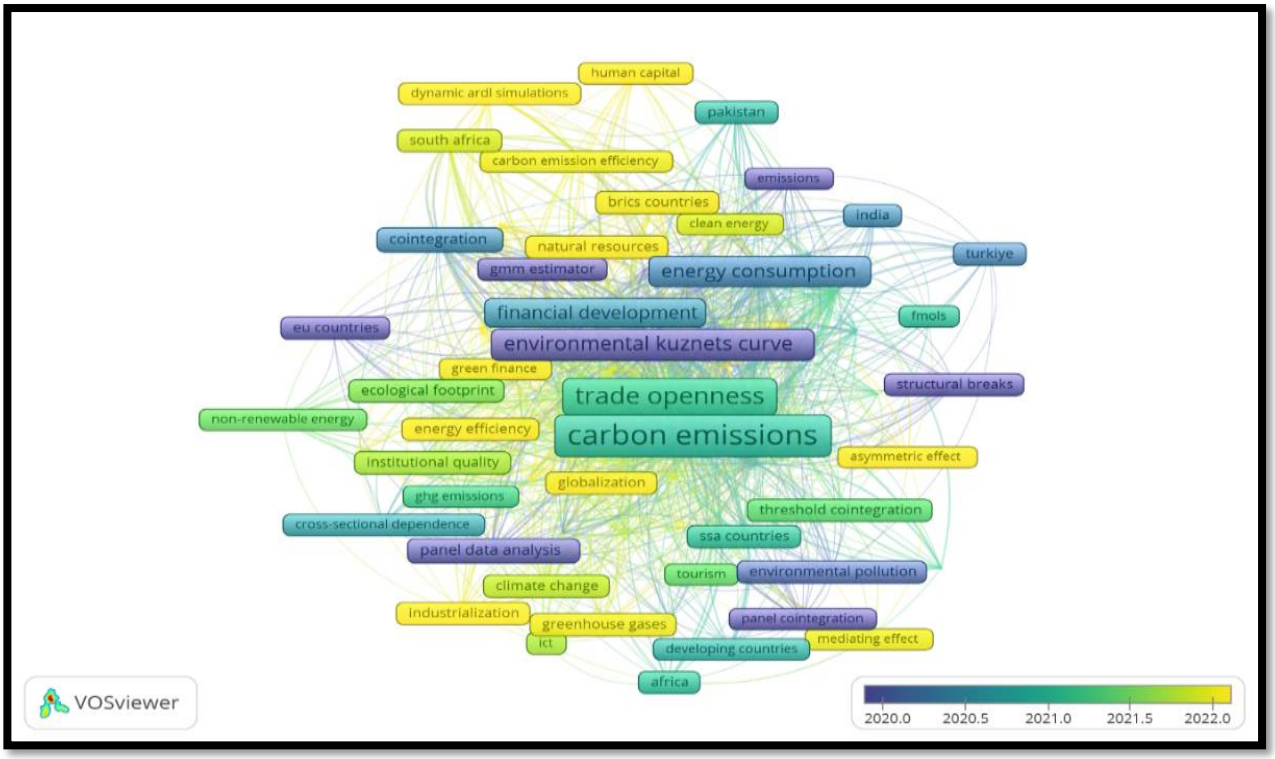

Figure 5: Overlay Visualization Map of the Co-Occurrence based on Average Publications per year using VOSviewer

CONCLUSION

The primary focus of this study is to provide a bibliometric analysis on the relationship between TO and CE. The data is obtained from the Scopus database from the period from 2005 to 2024 by employing biblioMagika, OpenRefine, and VOSviewer. The results show a steady increase in academic research in the TO and CE domain, with 2023 registering the highest number of publications. The study offers a comprehensive overview of the existing study through the research landscape, examining publication by authors and countries, identifying the highly cited documents, determining the top keywords, and conducting the co-occurrence analysis. Therefore, these findings from current studies will be crucial in guiding the direction of future research. Nonetheless, there are limitations of this study that can be addressed in future studies. Firstly, the data employed in this study is dynamic and may change over time as the citation counts for current publications rise. Next, this study only used data from the Scopus database; therefore, future studies could consider incorporating additional databases like Web of Science to complement the Scopus database and provide a more comprehensive analysis. Also, future research could examine the integration of trade policy with climate change initiatives, assess the impact of digital trade, and analyze the varying effects of TO on CE across different economic sectors and regions. Hence, by tackling these research gaps, it will provide valuable insights to the researcher and policymakers alike.

Authors' Contribution

The authors declared that there is no conflict of interest in this article. All authors participated in the conceptualization of the article.

Disclosure of generative AI and AI-assisted technologies

In the preparation of this work, the authors employed QuillBot and ChatGPT to evaluate the language and improve readability. Subsequent to utilizing these tools, the authors assessed and refined the text as necessary, accepting full responsibility for the publication's content.

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