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Global Plastic Waste Trade: An Analysis of Sources and Trends (1996-2024)[1]

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Abstract

The trade in plastic waste plays a crucial role in the advancement of global waste management and recycling systems. Developed nations export plastic waste to developing countries, reducing environmental harm and creating economic opportunities. This study conducts a bibliometric analysis of 257 articles on plastic waste trade published between 1996 and 2024 in the Web of Science (WoS). The analysis highlights China's 2018 import ban as a key topic, with Chen, W.Q. identified as the most prolific author. Resources, Conservation and Recycling is the leading journal in this field. The study reveals China's unique academic characteristics compared to other countries, with the U.S. as the second most significant contributor. Key author keywords include waste, life cycle assessment, and circular economy. This research fills a gap in literature and aims to be a foundational resource for scholars in the field.

Keywords: *Plastic Waste Trade, Bibliometric Analysis, Bradford's Law, Citation Network Analysis.*

JEL Codes: *F10, F18*

INTRODUCTION

On a global scale, plastics have emerged as a significant commodity due to their advantageous properties, including lightweight nature, flexibility, and ease of shaping. Consequently, they are now ubiquitous in nearly every commercial product (Brooks et al., p.1; 2018; Liang et al., 2018, p.242). In contemporary society, plastics play a crucial role in the global economy as a fundamental material (Amadei et al., 2023, p.1). The United Nations Environment Programme (UNEP, 2022) reports that annual global plastic production increased dramatically, doubling from 234 million metric tons (mt) in 2019 to 460 million mt in 2020. According to the year-end statistics published by Plastics Europe in 2022, global plastic production amounted to 400.3 million metric tons (MT). An analysis of the distribution of this volume by country reveals that 32% is attributed to China, 17% to North America, 14% to European Union member states, and 19% to other Asian countries excluding China (Plastics Europe, 2022)[4]. Furthermore, UNEP projects that global plastic production will reach approximately 1,231 MT

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[4] https://plasticseurope.org/wp-content/uploads/2023/10/Plasticsthefastfacts2023-1.pdf

by the year 2060 (UNEP, 2022, p.1). The role of plastics in international trade is also significant. The United Nations Conference on Trade and Development (UNCTAD, 2022) highlighted this situation, stating that if the global plastics trade were considered a country, it would rank as the fourth largest export market in the world. Exports of plastic waste increased from 218.2 million tons in 2005 to 381.8 million tons by 2021, with a monetary value of USD 1.184 billion. Similarly, plastic waste imports rose from 268.9 million tons in 2005 to 334.4 million tons in 2021, valued at $1.179 billion (UNCTAD, 2022).

In the wake of extensive production and manufacturing activities, the issue of plastic waste has emerged as a significant environmental challenge that is pertinent to nations and governing bodies globally. The improper disposal of plastic waste results in significant environmental harm, including pollution, contamination of the food chain, degradation of biodiversity, waste of energy resources, and economic losses. Most critically, it poses a threat to human health (Chow et al., 2017, p.125). The issue of unmanaged and mismanaged plastic waste is especially pronounced in developing countries, where the infrastructure for collection, reuse, and recycling is frequently insufficient or nonexistent (Browning et al., 2021, p.1). The establishment of a circular plastic economy has become critically important. This involves implementing processes for secondary use, recycling, and the responsible disposal of plastic. It is essential to adopt methods that minimize environmental harm throughout the entire lifecycle of plastic and its derivatives, from production to disposal, in order to promote sustainable production and consumption practices.

In developing countries, these challenges result in the uncontrolled release of waste into the environment, polluting water resources and soil, and worsening the living conditions of local communities. The inadequate management of plastic waste has significant detrimental effects on both marine and terrestrial ecosystems. Microplastics present in oceanic environments pose a threat to marine organisms, while their accumulation in terrestrial settings diminishes soil fertility and disrupts ecological balance. Consequently, it is imperative to enhance plastic waste management systems in developing nations and to foster international collaboration alongside sustainable waste management practices. The establishment of a circular plastics economy has become critically important, necessitating the implementation of processes such as secondary use, recycling, and responsible disposal of plastics. It is essential to adopt methods that minimize environmental harm throughout the entire lifecycle of plastics and their derivatives, from production to disposal, in order to promote sustainable production and consumption practices. The circular plastics economy seeks to minimize waste, promote the reuse and recycling of materials, and concurrently reduce resource consumption and environmental impacts. The effective implementation of these processes mitigates the adverse effects of plastic waste on the environment, safeguards ecosystems, and fosters economic and social sustainability. Furthermore, plastics that are reintegrated into the manufacturing sector through secondary use or recycling may be subject to international trade, as they frequently function as cost-effective intermediate inputs or raw materials. Brooks et al. (2018) indicate that plastic

waste that is not properly disposed of, recycled, or has potential for secondary use is often favored for trade. In this context, the concept of a global circular plastic economy can be discussed, wherein recyclable plastics are imported and utilized for secondary applications. This process involves transferring substantial plastic waste from one country to another, thereby reintegrating it into production cycles. International trade in plastic waste has the potential to yield both environmental benefits and economic opportunities. By facilitating the more efficient utilization of resources, such trade can mitigate the adverse effects of plastic waste on the environment. As a result, the longevity of plastics can be increased, and waste management systems can be improved, leading to sustainable waste management practices and enhanced resource efficiency.

The statistical changes in the import, export, and foreign trade volume of plastic waste, crumb, and scrap classified under NACE code 3915 worldwide from 2004 to 2022 are illustrated in Fig. 1.

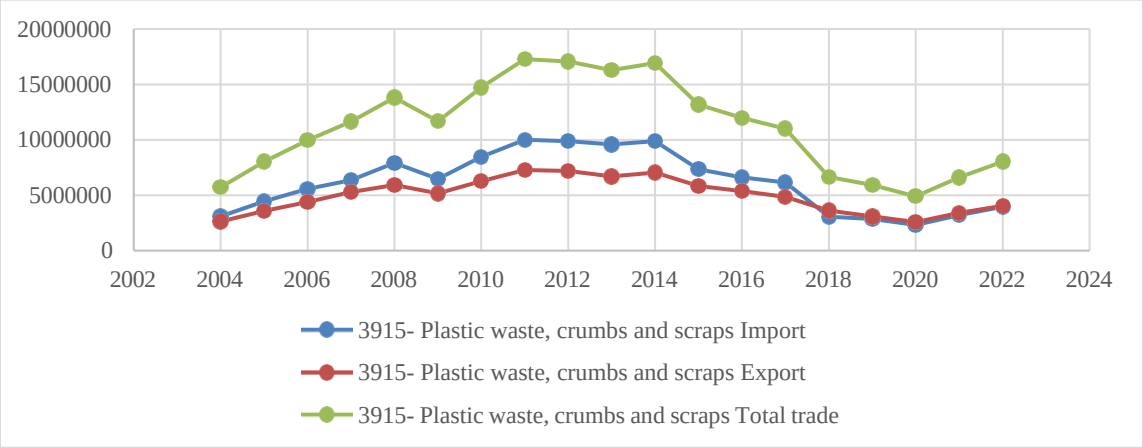


Figure 1: World 3915-Plastic Waste, Crumb and Scrap

Source: Plastics Waste, Crumbs and Scraps. www.trademap.org

According to statistics for the period from 2004 to 2022, as presented in Figure 1 and sourced from Trade Map, the total volume of foreign trade was approximately 5.7 million dollars in 2004, peaking at 17.2 million dollars in 2011. The trade in plastic waste exhibited relative stability, fluctuating between 16 and 17 million dollars from 2012 to 2014. However, following 2014, a notable decline ensued, with trade volumes falling below 6 million dollars in the years after 2017. The year 2017 is particularly significant for the evolution of the plastic waste trade, coinciding with China's implementation of a ban on plastic waste imports as part of its environmental protection policies. This ban, enacted in 2017, has had a profound impact on the sector, given that China accounted for 45% of plastic waste imports since 1992 (Brooks et al., 2018, p.2). The implementation of a ban on plastic waste imports by China, a significant contributor to both plastic production and imports, on January 1, 2018, resulted in a notable shift in the trajectory of plastic waste towards Malaysia and other Southeast Asian nations (Wang et al., 2019, p.9). However, as an increasing number of countries impose bans on plastic waste imports in response to environmental concerns, the dynamics of participation in this sector have evolved. Consequently, it has been observed that the global trade in plastic waste is predominantly concentrated among

Asian countries, as well as in North America, Europe, and Oceania (Zhao et al., 2021, p.9). According to statistics obtained from Trade map, prior to 2017, China accounted for nearly 50 percent of the world's plastic waste imports. However, following the implementation of a waste import ban in 2018, the United States and Hong Kong emerged as the leading importers of plastic waste. By 2020, it was observed that Hong Kong had nearly halved its plastic waste imports, with the United States and the Netherlands sharing the top position in plastic waste imports from 2020 onwards. By the year 2022, the Netherlands held the top position in plastic waste management, followed by the United States in second place and Turkey in third. Comprehensive data regarding the importation of plastic waste by countries is available in Appendix- 1.

There is an impression that the changing flow of plastic waste trade around the world has negative environmental and social impacts as well as economic impacts, and for this reason, countries have introduced some legal and regulatory obligations. It has been highlighted that, although public concern regarding plastic pollution is on the rise across various countries and regions, the scientific comprehension of this issue remains fragmented (Liang et al., 2021, p.243). From this perspective, it is essential to assess the extent of scientific research conducted by various countries regarding the trade of plastic waste, as well as their perspectives on this issue. In this context, it is important to examine how the evolving roles of countries in the plastic waste trade develop over time, in conjunction with research published in reputable academic journals. A systematic review of high-quality research in the field of plastic waste trade would be significantly advantageous. Such a review has the potential to enhance scientific understanding of the plastic waste trade and to identify existing knowledge gaps. Moreover, the current literature encompasses a diverse array of interdisciplinary studies that examine the plastic waste trade from various perspectives. However, it has been noted that the embodied and emerging aspects of plastic waste flows have not been thoroughly investigated, either quantitatively or qualitatively. This observation highlights the necessity for a more comprehensive and holistic analysis to better comprehend the dynamics and global implications of the plastic waste trade. Therefore, a meticulous examination of scientific research on the plastic waste trade is essential for understanding current challenges and for formulating future policy and practice recommendations. This approach can facilitate the development of more effective strategies for plastic waste management and promote international collaboration. To address this gap in literature and contribute to the advancement of the field, this study conducts a systematic review of the embodied flows associated with publications on plastic waste trade. In this review, bibliometric and social network analyses were employed. The primary objective of the research is delineated into the following four sub-objectives:

I. To elucidate the research dynamics within the field by examining the trends, developmental patterns, and characteristics of publications related to plastic waste trade from 1996 to 2024.

II. To identify existing perspectives and potential biases by evaluating the contributions of research on the trade of plastic waste, categorized by country, institution, author, and journal.

III. Identifying New Areas of Research through Co-Citation Relationships: This section aims to identify novel and emerging research domains by analyzing keywords and co-citation relationships, while also evaluating their contributions to the scientific understanding of plastic waste trade.

IV. To delineate prospective research directions and strategies pertaining to the trade of plastic waste and international trade research, with the objective of informing knowledge and practice within this field.

METHODOLOGY

Bibliometric analysis systematically examines publication and citation data within a specific research domain to evaluate research outputs and impacts, as well as to identify emerging trends (Khatun et al., 2021, p.2). This analytical approach, utilized to investigate and interpret extensive volumes of scientific data, provides a comprehensive overview of the evolutionary development of a particular field while also assisting in the identification of new directions and trends (Donthu et al., 2021, p.285). Bibliometrics constitutes an essential component of research evaluation methodologies across both scientific and applied disciplines (Ellegaard and Wallin, 2015, p.1809). The bibliometric methodology enables the discovery, organization, and analysis of substantial datasets (Daim et al., 2006, p. 985). Moreover, such analyses yield valuable insights for researchers aiming to assess scientific activities (Duque Oliva et al., 2006, p.231).

Hulme (1923) characterized bibliometrics as “statistical bibliography”, Pritchard (1969) further defined bibliometrics as the application of mathematical and statistical methods to the analysis of books and other sources. Cobo et al. (2011) identified two primary approaches to bibliometric analysis: performance analysis and scientific mapping. Performance analysis assesses the impact and contributions of publications, authors, and journals within a specific research domain, whereas scientific mapping visualizes relationships and trends in the literature, thereby enhancing the understanding of the structure and evolution of the field (Cobo et al., 2011, p. 146). Various derived indicators, such as the number of publications and citations in the scientific literature, along with phenomena including citation, co- authorship, and concentration in influential journals, are collectively referred to as bibliometric indicators (Narin and Hamilton, 1996, p.293). To derive these indicators, a range of software options is available, including Bibeexcel, Citespace, Biblioshiny, Histcite, Ucinet, Pajek, Vivo, Gephi, Vantage Point, VOSviewer, and Scimat. In this study, the Biblioshiny program, which is part of the bibliometrics package (Derviş, 2019, p.158) in the R programming language—comprising over 16,000 open-source software packages—was employed.

ANALYSIS AND FINDINGS

Data for this bibliometric analysis were obtained from the Web of Science (WoS). Figure 2 presents the methodology flowchart. The searches are limited to the period from 1996 to February 2024.

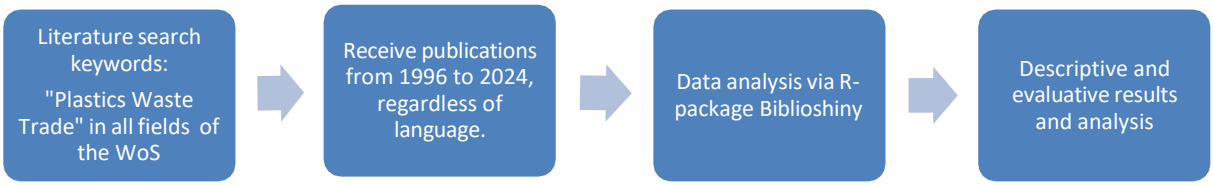


Figure 2: Methodology Flowchart

Source: Created by authors.

The primary statistics regarding scientific publications on the trade of plastic waste for the period from 1996 to 2024 are presented in Table 1.

Table 1: Main Information About Data

Description	**Results**
Timespan	1996:2024
Sources (Journals, Books, etc.)	144
Documents	257
Annual Growth Rate %	2,51
Document Average Age	5,24
Average citations per doc	31,24
References	12790
Document Contents	**Results**
Keywords Plus (ID)	684
Author's Keywords (DE)	868
Authors	**Results**
Authors	923
Authors of single-authored docs	32
Authors Collaboration	**Results**
Single-authored docs	35
Co-Authors per Doc International co-authorships	3,81
%	28,79
Document Types	**Results**
Article	208
Article; Early Access	1
Editorial Material	4
Proceedings Paper	13
Review	30

Source: Created by authors.

According to Table 1, a total of 257 studies across various research types have been published over a span of approximately 30 years, with 208 of these being articles authored by 923 researchers in the field. This calculation yields an average of 9 publications per year concerning plastic waste trade. Furthermore, the annual growth rate for publications in this area is calculated to be 2.51%. Notably, it was found that only 32 authors have contributed to the literature independently. The average age of the publications is 5.24 years, suggesting that interest and awareness in this research domain are relatively recent.

Figure 3 illustrates the annual distribution and number of citations for studies published in the field of plastic waste trade since 1996.

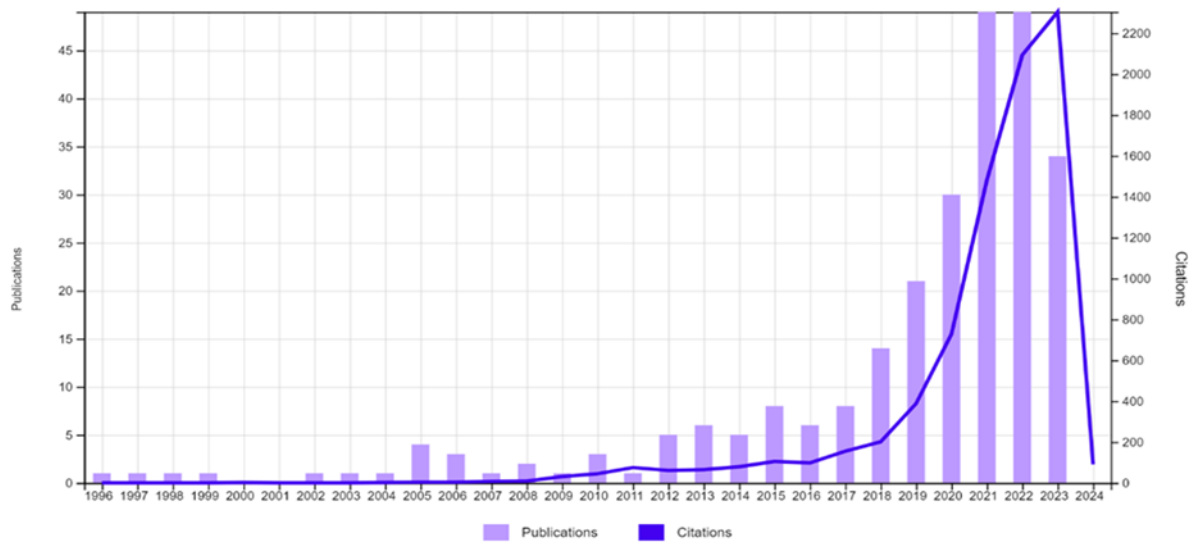


Figure 3: Annual Scientific Production and Citations

Source: Created by authors.

According to Figure 3, while there was a notable increase in the number of publications in the years 2005, 2006, and 2010, the most significant growth occurred after 2012. On the other hand, it is observed that the number of citations has exhibited an upward trend since 2008, culminating in a total of 2,200 citations in 2021 and 2022, and approximately 1,600 citations in 2023[5]. These statistics indicate that the trade of plastic waste is emerging as a subject of intensive scholarly inquiry.

The analysis of the distribution of publications by country reveals a notable concentration of academic interest in the trade of plastic waste, particularly in nations that are significantly affected by the environmental repercussions and resource implications associated with this trade. In these countries, the challenges posed by plastic waste are directly encountered, leading to an increased volume of academic research on the subject. Table 2 illustrates the 15 countries that have produced the highest number of publications regarding the plastic waste trade since 1996.

[5] Since the data obtained from the WoS was downloaded on February 6, 2024, the number of citations and publications has not yet been established. Consequently, in Figure 3, both the number of citations and the number of studies appear to exhibit a downward trend after 2023.

Table 2: The Most Relevant Countries for Plastics Waste Trade

Countries	No. of Publications	Percent (%)
China	113	43,9%
USA	85	33,1%
UK	58	22,6%
Japon	32	12,5%
Canada	31	12,1%
Italy	24	9,3%
Netherlands	23	8,9%
Germany	21	8,2%
Australia	19	7,4%
India	17	6,6%
Pakistan	17	6,6%
Sweden	12	4,7%
Brazil	12	4,7%
Nigerya	11	4,3%
Türkiye	9	3,5%

Source: Created by authors.

Among the countries examined, China exhibits the highest volume of publications in the domain of plastic waste trade, accounting for nearly half (113) of the total 257 publications attributed to researchers from various nations. The United States ranks second, with 85 publications. The United Kingdom (58) distinguishes itself in terms of publication volume among other countries, while Japan (32) and Canada (31) collectively contribute approximately 12-13% of the total publications. It is noteworthy that a portion of these publications arise from collaborative efforts between countries. Cross-national collaborations are illustrated in Figure 4, which delineates the extent to which countries engage in both national and international cooperation in their publications concerning plastic waste trade. Specifically, each country is categorized into two distinct authorship classifications: Single Country Production (SCP) and Multi-Country Production (MCP).

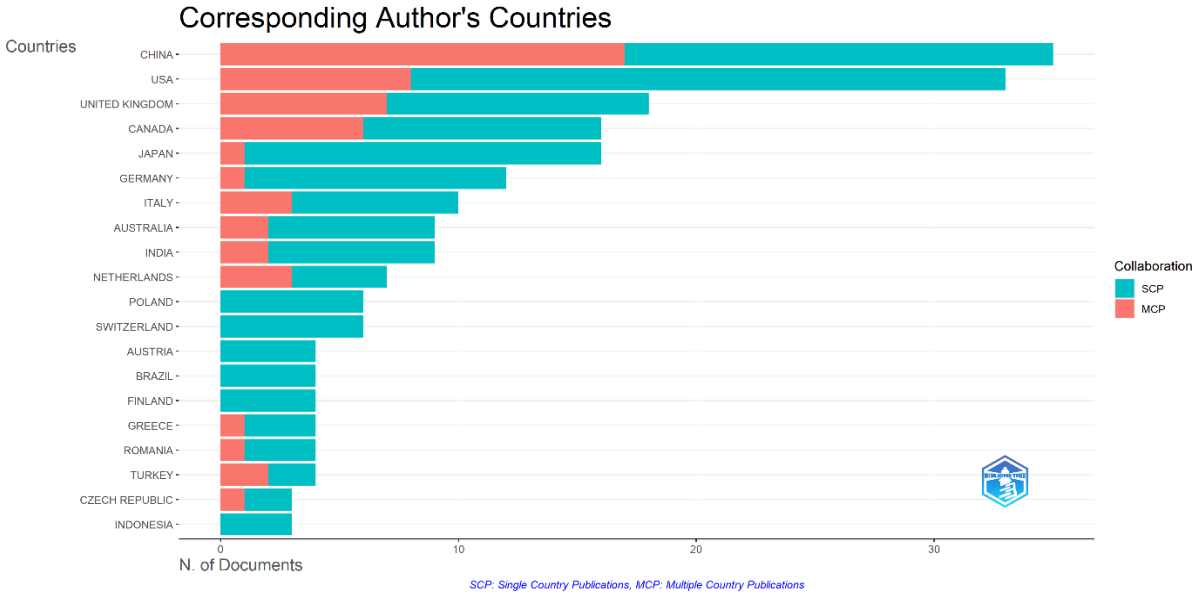


Figure 4: Local and Global Collaborations Among Authors in Countries Addressing Plastic Waste Trade

Source: Created by authors.

An analysis of the collaboration among the authors' respective countries reveals that China leads in both international and national production. It is the nation with the highest number of publications in this field. Notably, 18 out of the 35 active authors have published exclusively within China, indicating a focus on national collaboration. In contrast, the remaining 17 researchers have engaged in collaborative efforts with scholars from other countries. Among the 20 countries with the highest number of publications, as illustrated in Figure 4, it was observed that Poland, Switzerland, Austria, Brazil, Finland, and Greece exclusively engaged in national collaborations. In contrast, authors from other countries demonstrated a tendency to conduct joint studies with collaborators from at least one other nation. However, it is noteworthy that national collaboration (SGP) was generally favored over international collaboration (MGP).

Conversely, Figure 5 presents an analysis of the countries with the highest number of cited publications.

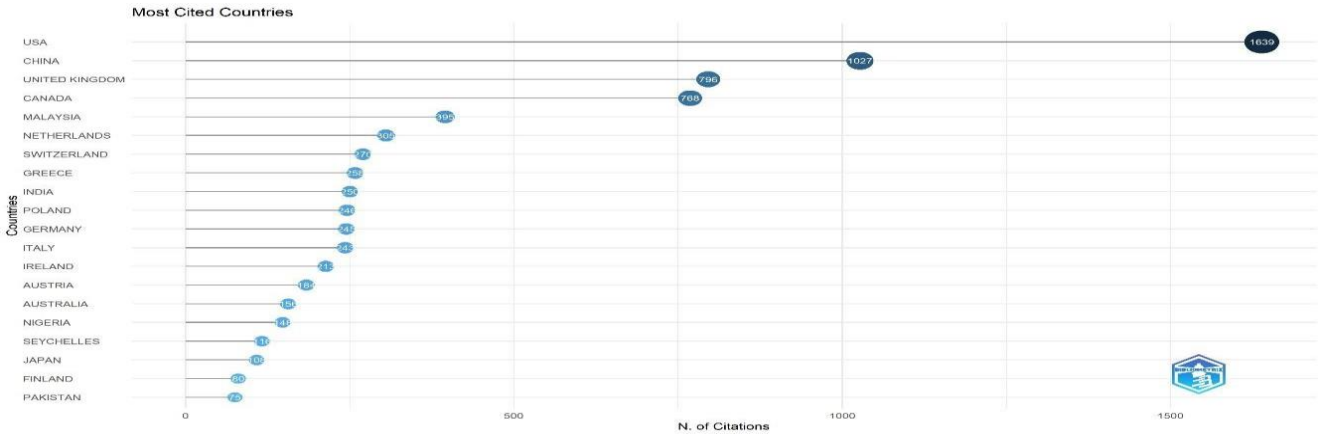


Figure 5: Most Cited Countries

Source: Created by authors.

Among the 20 countries exhibiting the greatest citation counts, the United States holds the leading position with 1,639 citations, followed by China, which has recorded 1,027 citations. When assessing the level of scientific research across various countries, it can be observed that while China is the most productive and engaged nation in this domain, it falls short of the United States in terms of scientific impact, as evidenced by citation counts. Nevertheless, China remains a leader in scientific impact relative to other countries, and the substantial volume of research conducted indicates a significant level of expertise in the field.

Another outcome of bibliometric analyses is the assessment of the output produced by affiliations within countries that are specific to the subject under investigation. The findings of this analysis are presented in Table 3. Table 3 demonstrates that China leads in the realm of academic institutions, as five of the top ten institutions with the highest publication output are in China. This phenomenon can be attributed to China's longstanding preference for the importation of plastic waste. However, researchers are increasingly considering the saturation of economic benefits derived from this practice, alongside the associated environmental challenges it poses as a detrimental outcome**.**

Table 3: Most Relevant Affiliations

No. of Publications	Affiliations	Countries
15	Chinese Academy of Sciences	China
6	Eth Zurich	Germany
6	Institute Of Urban Environment, CAS	China
6	Shanghai Jiao Tong Unıversıty	China
6	Tsinghua University	China
5	Swiss Federal Institutes of Technology Domain	Sweden
5	United States Department of Energy (DOE)	USA
4	Beijing Normal University	China
4	Brunel University	England
4	Comsats University Islamabad (CUI)	Pakistan

Source: Created by authors.

Following an examination of the contributions made by various countries and institutions, researchers within the field were also analyzed. In addition to the quantity of publications produced by the authors, the total number of citations and other references to a scientific publication are among the most commonly utilized bibliometric indicators for evaluating the quality of an author's work (Duque Oliva et al., 2006, p.231). It is essential to recognize that the mere quantity of publications does not adequately reflect the quality or impact of these works. In this context, the h-index serves as a metric that encapsulates both the impact and quality of publications. Moreover, the h-index illustrates the academic influence of countries, regions, institutions, and authors within the field (Bornmann et al., 2011, p.346). Table 4 displays the number of publications, total citations, h-index values, and citation-to- publication ratios for the 15 researchers with the highest publication counts in the respective field.

Table 4: Authors Publishing on Plastic Waste Trade: 1996-2024.

Ranking	Author	No. of Publications	Total Citation	h- index	Citation/Publication
1	Chen, WQ.	6	369	6	61,5
2	Walker, TR.	4	141	3	35,25
3	Briassoulis, D.	3	197	3	65,66
4	Dauvergne, P.	3	223	1	74,33
5	Hellweg, S.	3	141	3	47
6	Hiskakis, M.	3	197	3	65,66
7	Iacovidou, E.	3	176	3	58,66
8	Ma, ZJ.	3	171	3	57
9	Abbasi, S.	2	32	1	16
10	Adams, M.	2	125	2	62,5
11	Babou, E.	2	156	2	78
12	Barnes, SJ.	2	158	2	79
13	Beckham, GT.	2	127	2	63,5
14	Bing XY	2	152	2	76
15	Borrelle, SB.	2	11	2	5,5

Source: Created by authors.

According to Table 4, Wei-Qiang Chen (Chen, W.Q.) from the Chinese Academy of Sciences is identified as the most prominent researcher in the field, having authored a total of six publications and garnered 369 citations. The author with the highest h-index value was Chen, W.Q. His h-index is 6. Chen, W.Q. is followed by Tony R. Walker (Walker, T.R.) from Dalhousie University in Canada, who has authored four publications and garnered 141 citations. Walker, T.R.'s h-index is 3. The third most significant researcher is Demetres Briassoulis (Briassoulis, D.) from the Agricultural University of Athens in Greece, with three publications and 197 citations. An overall analysis of Table 4 indicates that a substantial majority (95%) of authors engaged in the field of plastic waste trade have published only a single article; specifically, 887 out of 932 authors have contributed to just one publication.

The distribution of publication years for the authors within the specified research period is illustrated in Figure 6. Notably, Chen, W.Q. emerges again as one of the most prominent figures among the top 15 researchers, Chen, W.Q.'s inaugural publication was released in 2019, followed by three publications in 2020 and two in 2021. Importantly, Chen, W.Q. achieved a total of six publications over the span of three years, which were the most cited among the top 15 authors. This may suggest that these publications have made significant scientific contributions to the field.

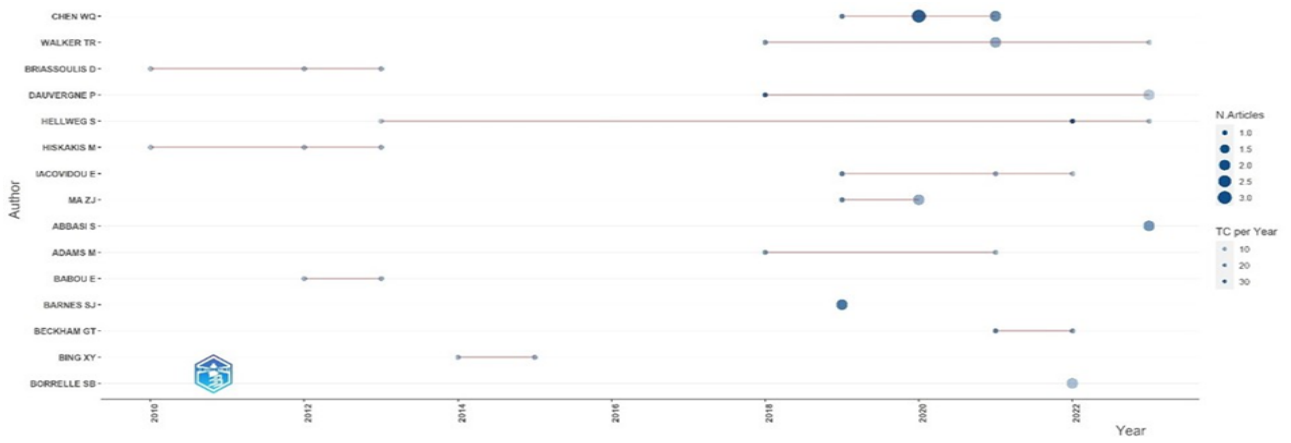


Figure 6: Authors' Production over Time

Source: Created by authors.

Chen, W.Q.'s inaugural article, entitled “Implications of China's Foreign Waste Ban on the Global Circular Economy,” was published in 2019 and has been cited 125 times in discussions pertaining to the trade of plastic waste. This article examines the ramifications of China's 2018 prohibition on plastic waste trade for the global circular economy. Additionally, another study authored by Chen, W.Q in 2020, titled “Structure of the Global Plastic Waste Trade Network and the Impact of China's Import Ban,” delineates the global plastic waste trade networks from 1988 to 2017 and assesses the implications of China's ban on plastic waste imports for these networks.

Additionally, in the same year, Chen published “Sustainable Cycles and Management of Plastics: A Brief Review of RCR Publications in 2019 and Early 2020.” This publication presents a meta-analysis of 11 articles on plastic circularity published in *Resources, Conservation and Recycling*. Another article from 2020, titled “Evolution of the Global Polyethylene Waste Trade System,” examines the mapping of polyethylene waste trade networks in the context of China's plastic waste import bans implemented in 2017.On the other hand, when the most cited publications in the field are analyzed, it is seen that the study titled “The Chinese Import Ban and Its Impact on Global Plastic Waste Trade” by Brooks et al. in 2018 received more citations than the study by Chen, W.Q. This article received 459 citations in total, making it the most cited publication on the subject. In the same year, Chen, W.Q. published the article titled “Sustainable Cycles and Management of Plastics: A Brief Review of RCR Publications in 2019 and Early 2020.” This publication provides a meta-analysis of 11 articles concerning plastic circularity that were published in *Resources, Conservation and Recycling*. Another article from 2020, entitled “Evolution of the Global Polyethylene Waste Trade System,” investigates the mapping of polyethylene waste trade networks in light of China's plastic waste import bans that were enacted in 2017.

Conversely, an examination of the most frequently cited publications within the field reveals that a particular publication by another researcher has garnered more citations than those authored by Chen, W.Q. This notable

work is the article titled "The Chinese Import Ban and Its Impact on Global Plastic Waste Trade, by Brooks et al. in 2018, which has accumulated a total of 459 citations. However, this article examines China's ban on plastic waste imports and the subsequent alterations in the flow of plastic waste trade resulting from these prohibitions. Additionally, it highlights the significance of global initiatives and actions aimed at the reduction, recycling, and local management of non-recyclable plastic waste, viewed through the lens of a circular economy.

The other most cited publications in the field are presented in Table 5.

Table 5: Top 10 Most Cited Publications

Author/ Authors	Citations
Brooks, A. L., Wang, S., & Jambeck, J. R. (2018).	459
Rosenboom, JG., Langer, R. & Traverso, G. (2022)	395
Sumathi S, Chai, S.P., & Mohamed, A.R. (2008)	384
Nguyen, B., Claveau-Mallet, D., Hermandez, L.M., Xu, E.G., Farner, J.M. & Tufenkji, N. (2019).	339
Urbanek, A.K., Rymowicz, W. & Mirończuk, A.M (2018)	228
Dauvergne, P. (2018).,	222
Domenech, T., Bleischwitz, R., Doranova, A., Panayotopoulos, D., & Roman, L. (2019).	159
Vanegas, P., Peeters, J. R., Cattrysse, D., Tecchio, P., Ardente, F., Mathieux, F., ... & Duflou, J. R. (2018).	138
Wen, Z., Xie, Y., Chen, M. (2021)	137
Sharkey M, Harrad, S., Elwafa Abdallah, M.A., Darage,D.S. & Berresheim, H. (2020), .	136

Source: Created by authors.

An additional observation regarding the most frequently cited articles presented in Table 5 is that these articles encompass central themes, including the circular plastic economy and marine pollution resulting from plastic waste. Furthermore, they underscore China's prohibition on the importation of plastic waste.

The most relevant journals and sources pertaining to the trade of plastic waste are presented in Table 6.

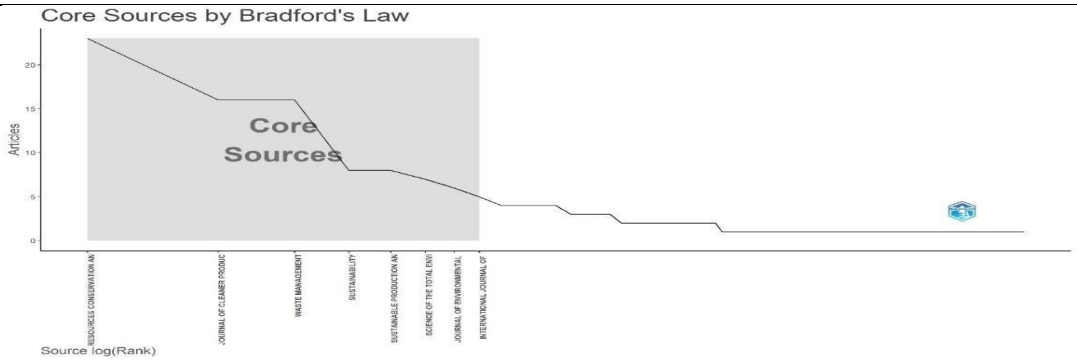
Table 6: Most Relevant Sources

Journals/ Sources	No of Publications	Total Citations
Resources Conservation and Recycling	23	1298
Journal of Cleaner Production	16	524
Waste Management	16	723
Sustainability	8	73
Sustainable Production and Consumption	8	79
Science of the Total Environment	7	87
Journal of Environmental Management	6	109
International Journal of Environmental Research An Public Health	5	47
ACS Sustainable Chemistry & Engineering	4	119
Environmental Science & Tecnology	4	125

Source: Created by authors.

Table 6 indicates that *Resources, Conservation and Recycling* was the most frequently cited source, with a total of 1,298 citations. This journal is primarily edited by individuals from the United States (19 editors) and

China (16 editors)[6]. Following this, both the *Journal of Cleaner Production* and *Waste Management* contributed 16 publications related to plastic waste trade. Nevertheless, *Waste Management* exhibited a higher scientific impact, recording 723 citations, in contrast to the 524 citations attributed to the *Journal of Cleaner Production*. An additional output of the bibliometric analysis is the identification of core sources pertinent to the researched topic. The distribution of publications concerning plastic waste trade, in relation to their sources, was examined utilizing Bradford's Law, as illustrated in Figure 7. According to this law, the concept of core publications implies that approximately one-third of the articles on the subject are disseminated by a specific group of journals, another one-third by a second group of journals, while the remaining articles are published by a larger array of journals (Garfield, 1980, p.477). On the other hand, this law indicates the core area of the most relevant journals for a particular field (Venable, et al. 2016, p.569).



Core sources Total percent	89 %34

Figure 7: Core Sources on Trade in Plastic Waste: Bradford Law

Source: Created by authors.

Core sources pertaining to the trade of plastic waste encompass the following journals: Resources Conservation and Recycling (23 publications), Journal of Cleaner Production (16), Waste Management (16), Sustainability (8), Sustainable Production and Consumption (8), Science of the Total Environment (7), Journal of Environmental Management (6), and International Journal of Environmental Research and Public Health (5). Collectively, these journals account for 89 of the 257 total publications, thereby illustrating their substantial influence and alignment with Bradford's law. This finding highlights the primary sources that researchers interested in investigating the subject should consult.

Figure 8 illustrates the most utilized keywords pertaining to the primary theme of plastic waste trade. Accordingly, the first of the most frequently used keywords in the field is the word “waste” with a frequency of 32. The word “management” is second with a frequency of 27, and the word “life-cycle economy” is third with a frequency of 24. Another keyword that shows the frequency of studies that characterize plastic waste trade as a

[6] https://www.sciencedirect.com/journal/resources-conservation-and-recycling/about/editorial-board

measure, or a sub- concept of the circular economy is “circular economy” with a frequency of 15.

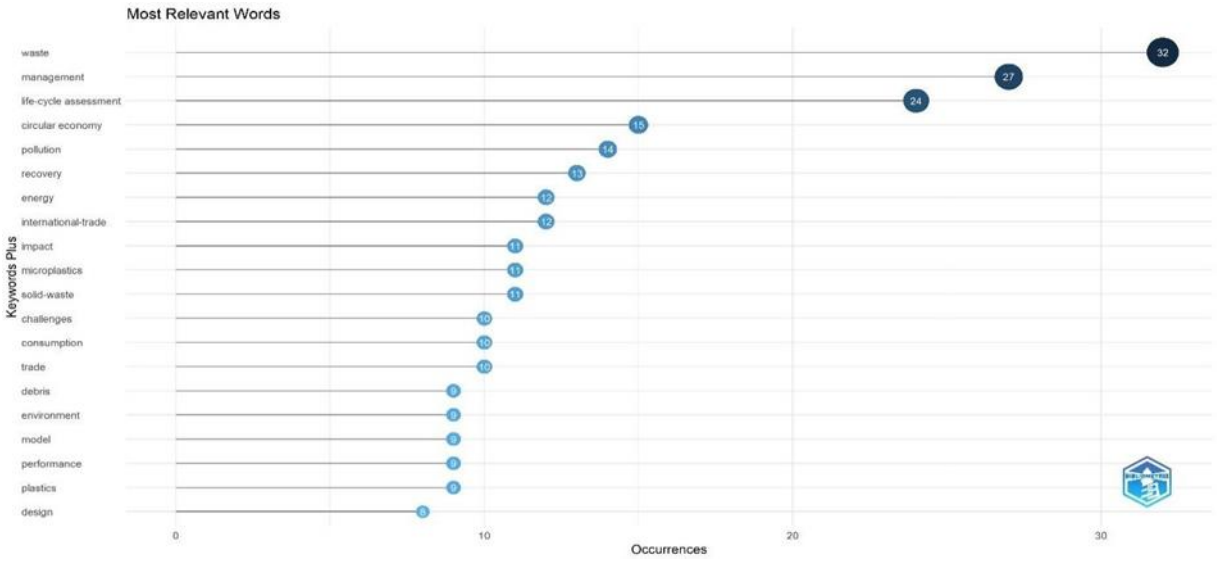


Figure. 8: Most Relevant Words

Source: Created by authors.

The initial scientific map that analyses global collaboration data pertaining to publications on plastic waste trade is the country collaboration map presented in Figure 9.

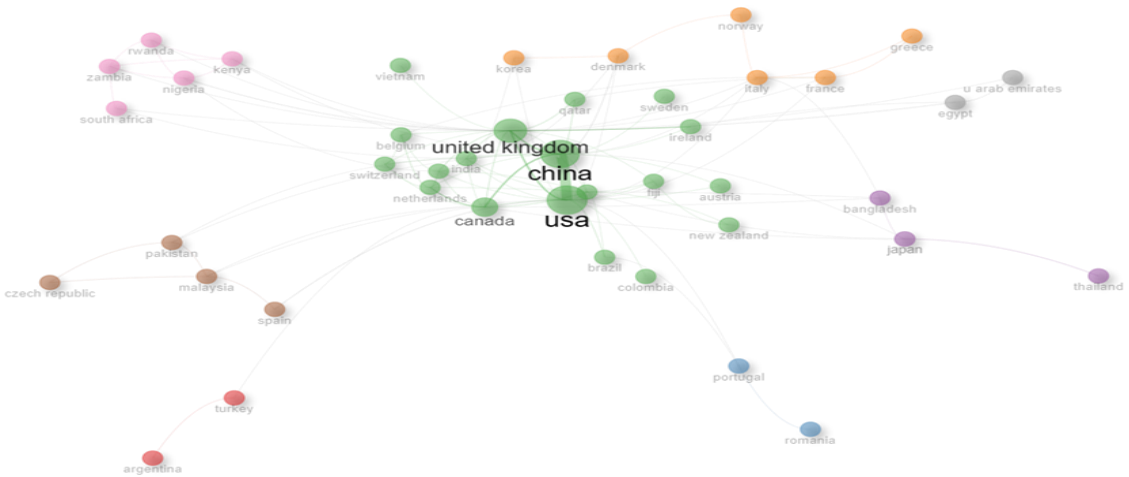


Figure 9: Collaboration Map of Countries

Source: Created by authors.

In the country collaboration map presented in Figure 9, the sizes of the circles correspond to the number of studies conducted, whereas the thickness of the lines reflects the degree of collaboration among the countries. The most substantial cooperation is observed between China and the United States, as indicated by a score of 9, followed by Canada and the United Kingdom, each with a score of 4. Additionally, the United States and the United Kingdom demonstrate a higher level of cooperation, with a score of 4, compared to other nations. These findings

are consistent with the data presented in Figure 5, which illustrates that China engages in the highest level of cooperation, as further depicted in Figure 9.

Another scientific map illustrating author collaborations is presented in Figure 10. This figure reveals a total of 11 distinct independent collaborations. The findings are consistent with those presented in Table 4, which indicates that Chen W.Q., who has the highest number of publications, is represented by the largest circle, thereby underscoring his position as the most collaborative author within his group.

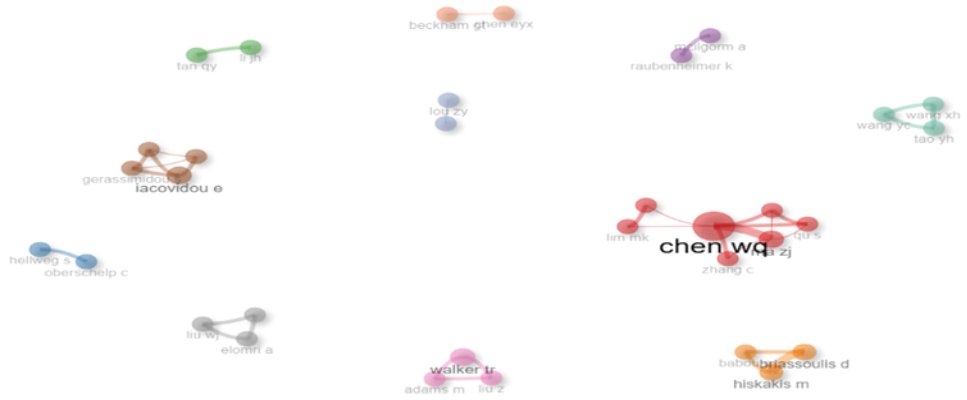


Figure 10: Author Collaboration

Source: Created by authors.

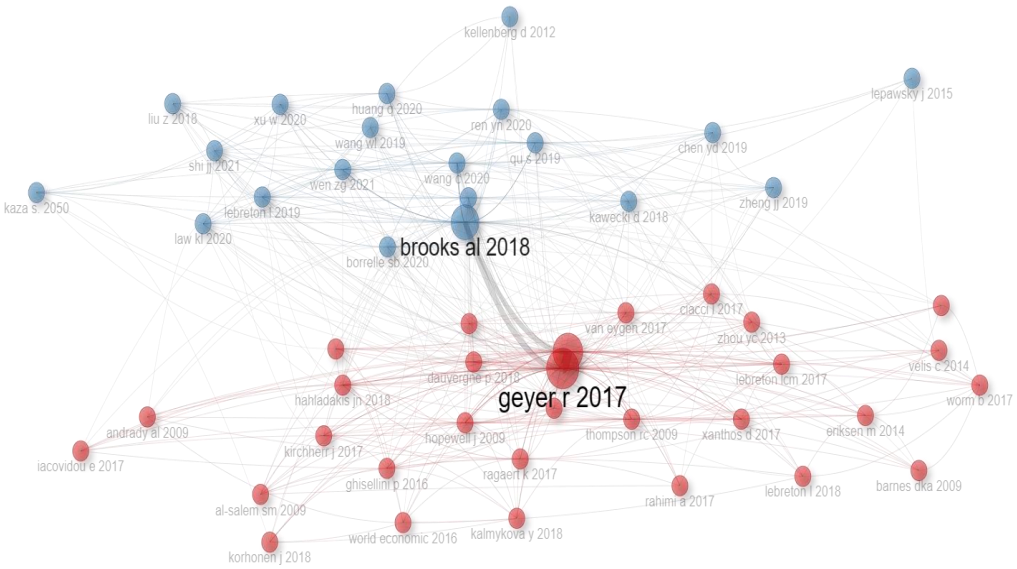


Figure 11: Citation Network Analysis between Publications

Source: Created by authors.

The citation network among publications represents another significant aspect of scientific mapping. As illustrated in Figure 11, two distinct clusters emerge from the citation analysis of these publications; however, there is a notable scarcity of citations between the clusters. Within the first cluster, the most frequently cited work is by Brooks et al. (2018), while the second cluster is predominantly represented by Geyer R.'s (2017) study titled

"Production, use, and fate of synthetic polymers". Geyer R. (2017) examines the global plastic sector, tracing its evolution from initial usage to waste management, and provides projections for the year 2050. When evaluating the citation analysis, it is evident that Geyer R.'s work serves as a crucial reference for other studies within its respective cluster.

Figure 12 presents three field plots that illustrate the interconnections among keywords, authors, and sources pertaining to the trade of plastic waste. The relationships among these three elements are depicted through gray linkages, which originate from the keywords-plus, connect to the authors, and subsequently link each author to the topics addressed in their publications. The size of each rectangle corresponds to the number of associated publications. Furthermore, the color intensity of the rectangles representing the units in the lists reflects their level of engagement with the subject matter. The width of the lines connecting the rectangles is indicative of the number of links. Notably, the author with the highest number of connections is Chen W.Q., who also leads in terms of publication volume. The most prevalent topics identified in the keywords-plus include circular economy, plastic waste, and recycling. Among the sources, Waste Management exhibits the most connections, followed by the Journal of Cleaner Production and Resources Conservation and Recycling.

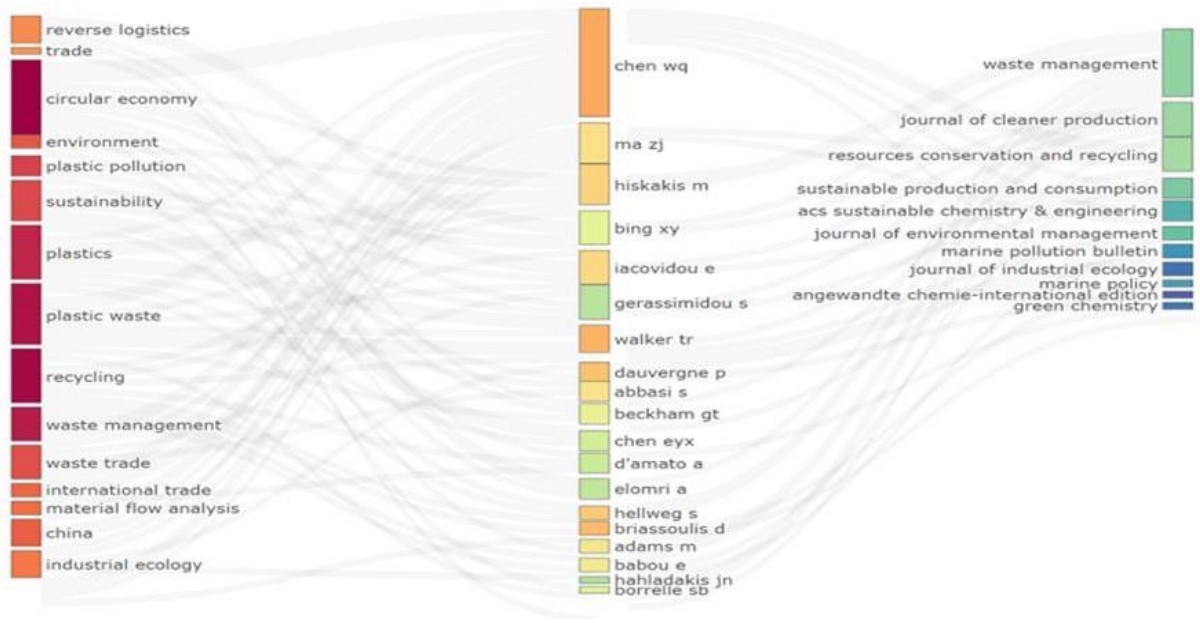


Figure 12: Three Field Plot

Source: Created by authors.

Biblioshiny provides a distinctive feature for the creation of thematic maps, which is not commonly available in other bibliometric software. Figure 13 illustrates the thematic map pertaining to publications on the trade of plastic waste.

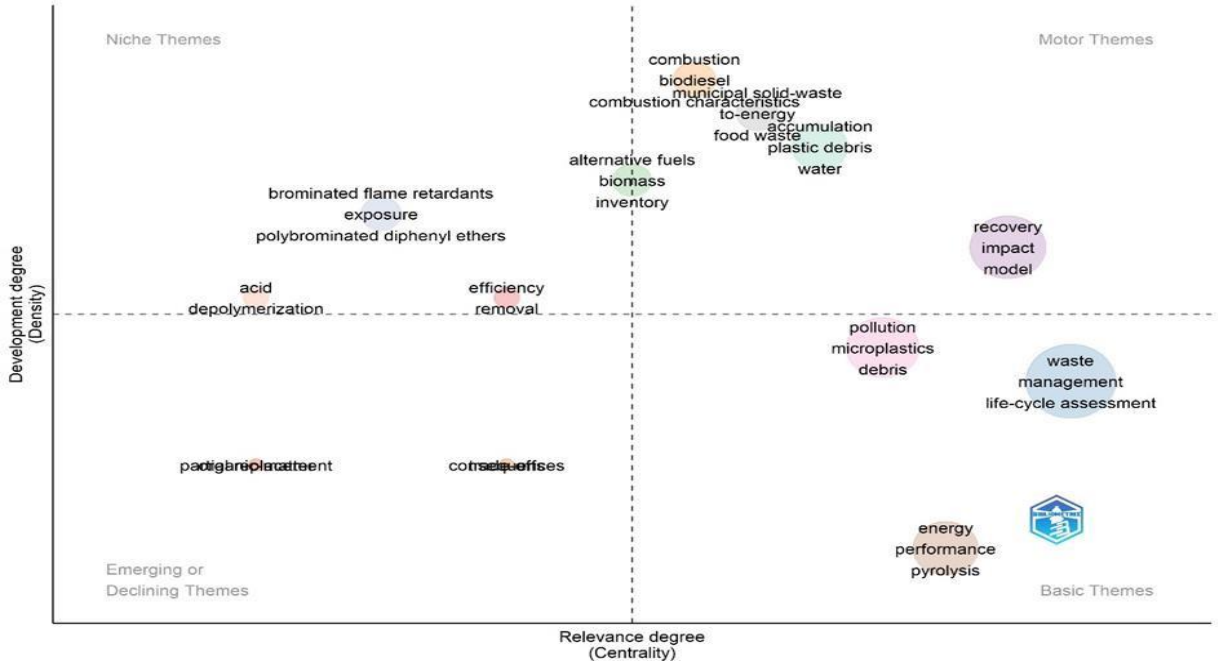


Figure 13: Thematic Map

Source: Created by authors.

As illustrated in Figure 13, the vertical axis of the thematic map represents the degree of development of the themes, commonly referred to as their intensity, while the horizontal axis indicates the degree of relevance to the subject, also known as the degree of centrality. The thematic map is divided into four quadrants based on the levels of centrality and intensity. The emerging or declining themes are in the lower left quadrant, while isolated and advanced (niche) themes are situated in the upper left quadrant. Basic or cyclical themes can be found in the lower right quadrant, and motor themes are positioned in the upper right quadrant.

As illustrated in Figure 13, the vertical axis of the thematic map represents the degree of development of the themes, commonly referred to as their intensity, while the horizontal axis indicates the degree of relevance to the subject, also known as the degree of centrality. The thematic map is divided into four quadrants based on the levels of centrality and intensity. The emerging or declining themes are located in the lower left quadrant, while isolated and advanced (niche) themes are situated in the upper left quadrant. Basic or cyclical themes can be found in the lower right quadrant, and motor themes are positioned in the upper right quadrant.

It can be asserted that the themes exhibiting the highest levels of centrality and intensity within these domains pertain to motor themes.

The map is divided into four quadrants: newly developing themes (lower left), isolated and developed themes (upper left), basic themes (lower right), and motor themes (upper right). Motor themes exhibit the highest centrality and intensity.

Motor themes identified in studies concerning the trade of plastic waste encompass 'incineration,' 'biodiesel,'

'municipal solid waste,' 'landfill,' 'food waste,' 'plastic debris,' 'recovery,' and 'mode of impact.'

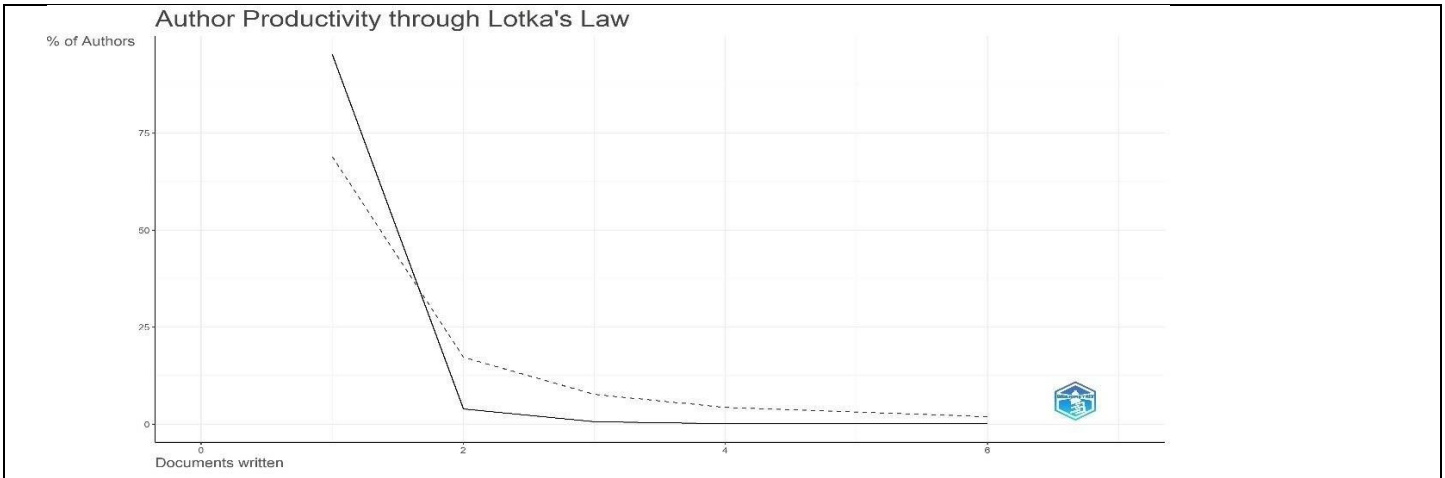
The isolated and advanced themes (niche themes), which are less centralized but have a high intensity of development in the field, include 'brominated flame retardants', 'exposure', 'polybrominated diphenyl ethers', 'acid', 'depolymerization', 'efficiency', and 'removal', all of which are pertinent to plastic recycling and plastic separation.

The thematic map analysis indicates that 'alternative fuels,' 'biomass,' and 'inventory' are significant themes that are extensively researched within the field, forming a cluster that connects motor themes with isolated themes.

Conversely, two distinct clusters of emerging themes have been identified: the first cluster pertains to 'partial replacement,' while the second cluster relates to 'exchange.' These clusters indicate novel research topics of significance within the domains of plastic waste recycling and exchange.

Finaly, fundamental and circular themes characterized by high centrality yet low development within the field encompass 'pollution', 'microplastics', 'debris', 'waste', 'management', 'life-cycle assessment', 'energy', 'performance', and 'pyrolysis'.

The Biblioshiny program also generates outputs that assess the productivity of authors within the field. The graph illustrating Lokta's law, which depicts the productivity of authors in the context of plastic waste trade, is presented in Figure 13. According to Lotka's law (1926), it is anticipated that 60% of authors will contribute to the literature with one article, 15% will contribute with two articles, and 7% will contribute with three articles (Lotka, 1926, p.318).



Number of Publications	Number of Authors	Author Rate (%)
1	879	95,2
2	36	3,9
3	6	0,7
4	1	0,1
6	1	0,1

Figure 14: Author Productivities according to Lotka's Law

Source: Created by authors.

According to Figure 4, a total of 879 authors, representing 95.2% of the authors in the field, have published a single article on the topic of plastic waste trade. This finding suggests a lack of collaboration among authors in this area, indicating that those who publish once are unlikely to produce subsequent publications. Consequently, it can be inferred that the authors engaged in this field exhibit inefficiency, as evidenced by the results aligned with the principles of Lotka's Law.

CONCLUSION AND DISCUSSION

This study conducts a bibliometric analysis of publications related to the topic of "plastic waste trade" within the Web of Science (WoS) database, covering the period from 1996 to 2024. The analysis encompasses all fields, including titles, abstracts, keywords, and subject categories. The findings indicate that China emerged as the most productive and significant country in this domain, with Chen W.Q. identified as the most influential author. Additionally, the Chinese Academy of Sciences was recognized as the leading institution, with five of the top ten relevant institutions also located in China.

During the research period, 43.9% of the 257 publications accessed originated from China, while 33.1% were from the United States. China exhibited the highest volume of publications. An analysis of the publications revealed that China was the country with the greatest number of collaborative publications with other nations, and the United States was identified as the country with which China had the most collaborative publications.

It can be asserted that China, which consistently emerges as a prominent player across various categories in the research findings, exerts a significant influence on the trade of plastic waste as well as on academic research within this domain. This phenomenon can be elucidated by the emergence of a significant research topic within the literature, particularly following the imposition of a ban on the importation of plastic waste in 2017. The issue is addressed in discussions surrounding the trade of plastic waste, notably in the most frequently cited publication on the subject. This ban serves as the central theme of the work by Brooks A.L. et al. (2018), which has garnered considerable attention in academic discourse. This is the primary subject of the most cited publication in 2018 authored by Chen, W. Q., who is recognized as one of the leading authorities in the field of plastic waste trade, too. Additionally, another significant finding of the research is that the key concepts identified in the literature encompass the specific ban under consideration, the impact of this ban on the flow of plastic waste, as well as themes related to the environment and pollution, sustainability, the circular economy of plastics, secondary use, reuse, production, waste management, and international trade.

The keywords exhibiting the highest frequency in the discourse on plastic waste trade are “waste”, “life-cycle economy” and “circular economy”. It can be asserted that the principles of “circular plastics economy”, which underscore the significance of cost-effective raw materials and resource efficiency and "life -cycle economy" which encompasses environmental protection and sustainability, constitute two pivotal frameworks for research

on plastic waste trade within the academic literature. The primary motivations for investigating the trade of plastic waste generally include environmental protection, sustainability, and the pursuit of affordable raw materials and resource efficiency. Addressing the challenges associated with plastic waste and its trade is imperative, particularly in the context of resource scarcity and environmental concerns. It can be anticipated that this issue will remain a central topic of discussion, especially concerning its environmental and economic implications.

In this context, international regulations and cooperation are pivotal in influencing policies regarding the trade of plastic waste. Specifically, the amendments to the Basel Convention enacted in 2019[7] seek to enhance the transparency and traceability of waste movements between countries, while also aiming to alleviate the environmental burden faced by developing nations. These regulations mandate that trade be conducted in a manner that is not only economically viable but also ethically sound and environmentally sustainable.

Nevertheless, disparities in capacity among nations, inequalities in recycling infrastructure, and deficiencies in technical expertise significantly diminish the efficacy of plastic waste management on a global level. This situation may result in the export of plastic waste from developed nations to developing countries, potentially leading to practices that pose significant risks to both environmental integrity and public health. In this context, the concept of "environmental justice" is also of great importance in terms of plastic waste trade. Consequently, the trade of plastic waste represents a complex phenomenon encompassing environmental, economic, and ethical dimensions. One of the primary approaches to reevaluating plastic waste pollution on a global scale in a more equitable and inclusive manner is through the lens of the Sustainable Development Goals, which emphasize the necessity of addressing this issue not solely as an environmental concern, but also as a matter of environmental justice (Stoll et al, 2020).

On the other hand, the research findings reveal that, over a period of 28 years, a total of 923 authors have published works pertaining to the trade of plastic waste, whereas 879 authors have contributed to only a single publication. This data suggests a low level of productivity within this field, as supported by Lotka's law. Nonetheless, it is crucial to recognize that there has been a significant increase in awareness regarding this issue, particularly in the aftermath of 2018.

According to Bradford's Law, which is a significant finding of the study that may assist new researchers interested in investigating the trade of plastic waste, the core sources of relevant literature include *Resource Conservation and Recycling*, * Journal of Clean Production*, and *Waste Management*. It can be asserted that these journals represent the primary resources for researchers seeking to investigate the trade of plastic waste.

[7] https://www.state.gov/key-topics-office-of-environmental-quality-and-transboundary-issues/basel-convention-on-hazardous-wastes/ Access date: 15.06.2025

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APPENDIX-I

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
World	9.887,92	7.340,58	6.625,88	6.147,45	3.047,88	2.847,75	2.318,31	3.197,69	3.963,72	
China	6.034,667	4.183,374	3.694,425	3.259,988	39.036	508	180	0	0	
Netherlands	270,10	217,50	194,74	208,89	194,16	188,77	175,10	300,91	412,27	300,64
USA	287,33	234,81	233,79	244,17	268,86	246,98	232,96	367,81	378,05	306,75
Türkiye	44,40	35,64	49,58	76,24	116,43	113,12	139,82	195,10	296,94	202,93
Germany	234,94	195,64	187,79	168,55	158,90	167,79	141,93	212,56	290,59	179,40
Vietnam	52,19	51,48	43,57	70,82	108,09	150,16	141,53	205,79	199,62	
Taivan	88,30	83,51	71,46	80,26	193,02	181,30	133,34	156,70	186,15	143,98
Belgium	134,39	130,68	133,07	121,91	111,25	93,99	76,11	127,85	181,50	127,33
Malaysia	71,93	62,26	66,27	114,24	183,45	110,14	167,30	169,78	173,55	173,80
Spain	51,41	45,40	40,52	50,35	67,09	70,74	52,26	90,36	170,50	91,77
Italy	113,34	92,86	103,88	113,80	109,45	87,03	72,21	109,62	139,97	110,46
France	65,73	48,57	48,26	55,69	73,09	77,16	67,51	81,00	139,25	57,84
Austria	89,64	69,44	55,64	48,88	58,43	61,43	54,68	96,87	122,38	89,60
Canada	96,84	87,70	75,83	70,08	73,58	72,57	69,87	107,10	108,02	80,33
Indonesia	52,50	42,74	42,48	45,87	102,37	83,22	63,04	79,58	103,41	
Poland	38,15	41,14	49,58	59,69	78,95	68,68	54,77	75,42	102,57	81,28
United Kingdom	85,63	54,15	67,74	60,15	68,40	74,81	50,56	43,28	74,93	61,42
Portugal	26,68	22,26	22,53	28,12	33,32	28,24	18,86	37,12	59,76	35,47
Mexico	18,83	22,47	21,58	23,20	21,47	21,38	28,77	52,35	58,66	
Slovenia	33,17	30,06	28,61	24,22	25,62	32,42	23,12	41,50	54,96	35,13
India	162,76	93,40	79,74	71,89	69,14	53,84	704,00	28,71	49,18	
Thailand	21,04	11,35	14,18	27,26	72,77	46,16	25,11	40,76	47,46	57,09