

BRIDGING THE GAP: A BIBLIOMETRIC ANALYSIS OF THE EPI AND ITS ROLE IN ADDRESSING ENVIRONMENTAL CHALLENGES

(Merapatkan Jurang: Analisis Bibliometrik EPI dan Peranannya dalam Menangani Cabaran Alam Sekitar)

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ABSTRACT

Organizations have increasingly recognized the importance of sustainability in recent decades. As a result, they have made significant efforts to develop specific metrics for the purpose of accurately evaluating sustainability. Environmental sustainability metrics are gaining popularity due to their significance in combating the climate crisis. These metrics help organizations that prioritize environmental initiatives to assess progress, monitor goals, and verify effectiveness by focusing on waste reduction and energy efficiency. The Environmental Performance Index (EPI) is a globally recognized tool used to evaluate the progress made by 180 countries in addressing climate change, environmental health, and ecosystem vitality. However, the EPI encounters several challenges in its role as the main indicator of environmental performance which include data gaps and inconsistencies in methodology. Quantifying the scientific production, quality, and impact of the EPI is crucial in assessing its relevance in academia, despite its current limitations. Therefore, a comprehensive bibliometric analysis has been conducted on 393 publications from the Scopus database, related to EPI. The bibliometric analysis explored on recent developments in this field, the diversity of countries and authors collaborations and an overview of the most frequently cited documents. The results showed that previous studies do not provide enough insights to resolve limitations as a whole, which may allow others to improve EPI reliability. The paper concludes with valuable insights on how modifying the existing metric while addressing its limitations based on previous research can change the future of EPI studies and improve their academic relevance.

Keywords: sustainability; EPI; bibliometric analysis; indicator; ranking; Scopus database

ABSTRAK

Organisasi telah semakin menyedari kepentingan kemampanan sejak beberapa dekad kebelakangan ini. Hasilnya, mereka telah melakukan usaha yang besar untuk membangunkan metrik khusus bagi tujuan menilai kemampanan dengan tepat. Metrik kemampanan alam sekitar semakin popular kerana kepentingannya dalam memerangi krisis iklim. Metrik ini membantu organisasi yang mengutamakan inisiatif alam sekitar untuk menilai kemajuan, memantau matlamat dan mengesahkan keberkesanan dengan memfokuskan pada pengurangan sisa dan kecekapan tenaga. Indeks Prestasi Alam Sekitar (EPI) ialah alat yang diiktiraf di peringkat global yang digunakan untuk menilai kemajuan yang dicapai oleh 180 negara dalam menangani perubahan iklim, kesihatan alam sekitar dan daya hidup ekosistem. Walau bagaimanapun, EPI menghadapi beberapa cabaran dalam peranannya sebagai penunjuk utama prestasi alam sekitar seperti jurang data dan ketidakkonsistenan dalam metodologi. Pengukuran pengeluaran saintifik, kualiti dan impak EPI adalah penting dalam menilai kerelevanannya dalam akademik, walaupun terdapat batasan semasa. Oleh itu, analisis bibliometrik yang komprehensif telah dijalankan ke atas 393 penerbitan daripada pangkalan data Scopus, berkaitan EPI. Analisis bibliometrik meneroka perkembangan terkini dalam bidang ini, kepelbagaian kerjasama antara negara dan pengarang, serta gambaran keseluruhan dokumen yang paling kerap dipetik. Keputusan menunjukkan bahawa kajian terdahulu tidak memberikan pandangan yang mencukupi untuk menyelesaikan batasan keseluruhan, yang mungkin membolehkan orang lain meningkatkan kebolehpercayaan EPI. Kertas kerja ini diakhiri dengan pandangan berharga tentang cara

mengubah suai metrik sedia ada sambil menangani batasannya berdasarkan penyelidikan terdahulu boleh mengubah masa depan penyelidikan EPI dan meningkatkan perkaitan akademiknya.

Kata kunci: kelestarian; EPI; analisis bibliometrik; penunjuk; kedudukan; pangkalan data Scopus

1. Introduction

In the modern era, there is a prevalent discourse surrounding the multifaceted challenges of sustainable development, which are frequently associated with the actions of negligent individuals. The increasing focus on sustainable development has led numerous nations to explore various strategies and best practices to enhance their sustainability levels (Mensah 2019). An enhanced sustainable development strategy enables the preservation of the well-being of both present and future generations within a global context characterised by swift advancements in science and technology. The United Nations (UN) adopted the Sustainable Development Goals (SDGs) in 2015, comprising a set of 17 objectives aimed at addressing various global challenges (United Nations 2015). These goals encompass a range of issues, including poverty eradication, inequality reduction, and climate change mitigation, with the target of achieving them by the year 2030. The present advancement necessitates a comprehensive sustainability approach, encompassing social, economic, and environmental dimensions (Purvis *et al.* 2019).

The issue of environmental sustainability has emerged as a prominent challenge and a widely discussed subject due to the confluence of population growth and escalating human-driven environmental exploitation (Arora 2018). The aforementioned situation has garnered considerable attention and elicited apprehension from every relevant party regarding the Earth's long-term capacity to sustainably generate natural resources. According to a report from the United Nations (UN), the current global population of 7.6 billion people will rise to 8.6 billion by 2030, 9.8 billion by 2050, and 11.2 billion by 2100 (United Nations 2022). This projected increase in population is expected to have negative implications for environmental sustainability, potentially leading to escalated levels of pollution and environmental degradation. An instance of this phenomenon can be observed in the escalating human engagement in the combustion of fossil fuels, the extensive utilisation of vehicles, and the practise of deforestation, all of which contribute to the emission of greenhouse gases. Furthermore, there has been a notable escalation in the quantity of non-biodegradable waste, particularly plastic, over the course of time (Abel *et al.* 2023; de Haan *et al.* 2023). This surge in waste includes hazardous and toxic substances, which contribute to the pollution of natural resources, the extinction of various species, and pose threats to human well-being. Identifying a solution to this issue is crucial to ensure equitable opportunities.

Setting up a comprehensive and methodical framework for environmental sustainability governance can be done with the help of a metric that shows how the environment is doing right now and identifies the main causes of environmental problems. Using this metric, one can effectively assess and compare the performance of various nations across temporal dimensions. This enables the diligent monitoring of policy implications and gauging progress towards established objectives that include increasing awareness regarding environmental concerns. Henceforth, it is essential to adopt an empirical and data-driven methodology in the realm of

environmental preservation, as it enables the identification of optimal approaches and challenges while shedding light on the triumphs and shortcomings of policy implementation within a given nation (Schmiedeknecht 2013). An escalating demand has begun to develop for the utilisation of methods based on data to gauge the ecological efficacy exhibited by a nation. Therefore, the Environmental Sustainability Index (ESI) was introduced as the inaugural index to assess the holistic advancement towards environmental sustainability within a nation, and publication occurred in the years 2000, 2001, 2002, and 2005 (SEDAC n.d.). ESI was constituted an integral component of a broader endeavour known as the Environmental Performance Measurement (EPM) Project and the primary objective of EPM was to achieve an evolution in environmental decision-making by improving its intellectual foundations through the utilisation of environmental indicators and statistical data (Schmiedeknecht 2013).

The predecessor to the Environmental Performance Index (EPI) can be traced back to the inception of the ESI (Schmiedeknecht 2013). These two indices were meticulously constructed by esteemed academic institutions, namely Yale University's Centre for Environmental Law and Policy and Columbia University's Centre for International Earth Science Information Network. This collaborative effort was further supported by the involvement of prestigious organisations such as the World Economic Forum and the Joint Research Centre of the European Commission, thus lending a significant degree of credibility to the development process. The emergence of novel metrics, such as the EPI, has precipitated a notable change in emphasis away from the advancement of the ESI. The EPI has been widely employed as a benchmark index that offers a convenient tool for policy makers, researchers, governments, and the general public to monitor and assess their country's performance in relation to peer nations in the context of environmental sustainability (Esty *et al.* 2008).

Unfortunately, Usubiaga-Liaño and Ekins (2021) stated that countries currently lack comprehensive metrics to effectively assess their environmental sustainability performance from a holistic standpoint. Commitment to environmental indicators, such as the EPI, can enhance the effectiveness of national and international policy in addressing environmental issues. Despite its usefulness, the EPI faces challenges in serving as the primary measure of environmental performance. These challenges include data gaps, inconsistencies in methodology, and a lack of systematic verification of reported figures by involved parties. This study is intended to analyse the current trends in the literature on global environmental performance assessment, specifically focusing on evaluating the effectiveness of the EPI measurement. By finding common methods and best practices from past research, new insights can be gained, which makes the EPI more important in academic discussion and allows us to address its limitations, specifically data gaps and methodological inconsistencies.

This will be done by conducting a bibliometric review of papers on EPI studies published in the Scopus database. Elsevier introduced Scopus in 2004 as a database that contains citations and abstracts from scientific publications. It has become a powerful tool for researchers, offering extensive coverage of peer-reviewed literature and robust search and analysis capabilities across various disciplines, including science, technology, medicine, social sciences, and arts and humanities. Its recognition and application are prevalent within the academic community, rendering it a significant tool for evaluating journal quality and impact. Indexing in Scopus signifies quality and impact for journals, thereby increasing the visibility and credibility of the research they publish. We utilize a software tool like VOSviewer to enhance clarity, readability, and insightfulness in this analysis, which effectively communicates research findings. VOSviewer is a software application developed for the construction and visualization

of bibliometric networks. This tool helps researchers understand the landscape of scientific literature by making maps that show different types of relationships, such as co-occurrence, co-citation, co-authorship, and bibliographic coupling. Hence, the tools that are using in this study are able to provide a thorough analysis of previous studies, allowing for the identification of their implications and insights into the future of EPI.

2. Environmental Performance Index (EPI)

The Environmental Performance Index (EPI) is an instrument that continues to be used and functioning as a global metric for assessing the degree to which nations have attained their established environmental policy goals. The EPI is a popular approach that assesses and ranks countries based on their environmental performance. It has garnered recognition as a potent instrument in the realm of politics, as evidenced by various scholarly works (Strezov *et al.* 2017; Baloch *et al.* 2020; Reverter *et al.* 2020). The EPI has also presented a comprehensive evaluation tool that distinguishes the leaders and laggards in terms of environmental performance. This scorecard serves as a valuable resource for nations seeking to enhance their environmental sustainability practises, providing a practical roadmap for emulating countries that have excelled in this domain. The use of EPI performance indicators offers a valuable way of discerning issues, establishing objectives, monitoring patterns, comprehending outcomes, and identifying optimal policy approaches. This aids nations in honing their strategies and refining their overall approach towards environmental sustainability.

The performance indicators encompass 11 issue categories, and the Environmental Performance Index (EPI) evaluates 180 countries according to their advancement in three policy objectives: enhancing environmental health, conserving ecosystem vitality, and mitigating climate change. Figure 1 depicts 40 distinct performance indicators, with each issue category and objective possessing unique performance characteristics. It is important to mention that the previous 2020 EPI report focused on two policy objectives, while the latest 2022 report has incorporated additional objectives pertaining to climate change.

CLIMATE CHANGE MITIGATION	CLIMATE	CO2 GROWTH RATE	CH4 GROWTH RATE	N2O GROWTH RATE	F-GAS GROWTH RATE	BLACK CARBON GROWTH RATE	PROJECTED 2050 EMISSIONS	CO2 FROM LAND COVER	GHG INTENSITY	GHG PER CAPITA
ENVIRONMENTAL HEALTH	AIR QUALITY	PM2.5	HOUSEHOLD SOLID FUELS	OZONE	NITROGEN OXIDES	SULFUR DIOXIDE	CARBON MONOXIDE	VOLATILE ORGANICS		
	WASTE MANAGEMENT	CONTROLLED SOLID WASTE	RECYCLING	OCEAN PLASTICS						
	WATER & SANITATION	UNSAFE SANITATION	UNSAFE DRINKING WATER							
	HEAVY & METALS	LEAD EXPOSURE								
ECOSYSTEM VITALITY	BIODIVERSITY & HABITAT	LAND BIOME PROTECTION (NATIONAL)	LAND BIOME PROTECTION (GLOBAL)	MARINE PROTECTED AREAS	PROTECTED AREAS REP. INDEX	BIODIVERSITY HABITAT INDEX	SPECIES PROTECTION INDEX	SPECIES HABITAT INDEX		
	ECOSYSTEM SERVICES	TREE COVER LOSS	WETLAND LOSS	GRASSLAND LOSS						
	FISHERIES	FISH STOCK STATUS	MARINE TROPHIC INDEX	TRAWLING & DREDGING						
	AGRICULTURE	SUSTAINABLE NITROGEN USE	SUSTAINABLE PESTICIDE USE							
	ACID RAIN	SO2 EMISSIONS	NOX EMISSIONS							
	WATER RESOURCES	WASTEWATER TREATMENT								

Figure 1: The Environmental Performance Index (EPI) framework for 2022 displays 3 policy objectives, 11 issue categories and 40 indicators (Wolf *et al.* 2022)

The EPI score is a comprehensive index that combines 40 performance indicators into a single value, representing a country's overall performance. This is achieved by assigning weights and calculating averages across all metrics. EPI converts the data into performance indicators, which are numerical values from 0 to 100. These indicators are used to assess performance, with lower values indicating poorer performance and higher values indicating better performance. A score of 100 indicates that the country has achieved the criteria for exceptional performance. The EPI uses the distance to target method to calculate the EPI score for each performance indicator. This method employs scale factoring using a country's figures for a single performance indicator, which will be compared to the highest and lowest performance benchmarks. A perfect EPI score of 100 will be reached if, for example, the best performance value for a given performance indicator is 10 and the performance value for a country is also 10. If the worst performance value for a specific performance indicator is 5, and a country's performance value for that indicator is also 5, it will result in a score of 0 for the EPI for that country. The EPI makes use of an indicator score with values ranging from 5 to 10 in order to compute the EPI score for countries. The indicator score can be obtained by using the following equation:

$$\text{Indicator Score} = \frac{(X-W)}{(B-W)} \times 100 \quad (1)$$

where X represents the performance value of a country, W represents the target value for the worst performance, and B represents the target value for the best performance.

The EPI outlines the process for setting goals and thresholds for each metric in its report. The EPI's best and worst targets have been determined through the following three stages: 1) Obtain approval from the applicable international agreement or institution; 2) Consult with experts for recommendations; and 3) Calculate percentiles, using the 95th or 99th percentile to determine the best performance target and the first or fifth percentile to determine the worst target.

Several key challenges were identified that highlight the limitations of EPI methodology, especially regarding data gaps and inconsistencies. At first, the EPI methodology encountered difficulties caused by asynchronous data series, characterized by datasets with varying start and end periods, gaps in temporal coverage, and certain indicators available for only one year. The inconsistency in the time series prevented the construction of a reliable dataset without the imputation of missing values, which may lead to misleading interpretations. Secondly, estimating trends or maintaining constant values to address these gaps may obscure real shifts in environmental performance, thereby creating an illusion of unresponsiveness to policy alterations. Finally, Arcagök (2024) examined the formation of composite indices such as the EPI, highlighting constraints associated with indicator availability, weighting, and data organization. The constraints may influence the index's accuracy and ability to gauge subtle environmental changes. Therefore, employing bibliometric analysis enables researchers to establish more standardized methods for assessing environmental performance, thereby reducing inconsistencies and gaps through the identification of common methodologies and best practices in this field of study.

3. Bibliometric Analysis Techniques

The use of bibliometric analysis has gained significant popularity as a way of investigating and examining extensive scientific databases, resulting in significant research influence (Donthu *et al.* 2021). Ellegaard and Wallin (2015) explained that citation analysis, keyword analysis, and content analysis were all used as part of bibliometric analysis methods to do quantitative analysis of written works. These approaches are still commonly used in bibliometric analysis as it can figure out how important a subject is, identify research trends, and give useful information about the topics of scholarly publications. Content analysis entails the examination of the substance of academic publications, including abstracts, entire texts, and keywords, with the purpose of identifying recurring patterns and trends in research themes and topics. Citation analysis is concerned with analyzing citations in scholarly publications in order to comprehend the influence and impact of research. An evaluation of publications' importance and visibility is done by looking at citation patterns, citation networks, and citation counts. Finding new areas of study is as easy as doing a keyword analysis, which entails looking at how often certain terms appear in academic papers. Additionally, in regard to qualitative aspects of research evaluation, a few other approaches have been implemented, including co-authorship analysis, journal analysis, and network analysis. According to Ellegaard and Wallin (2015), the number of co-authored papers and the number of international collaborations are frequently considered in the research evaluation process. This is because by conducting such that analysis, significant researchers, research groups, and collaborations within a particular field can be identified, and the relevance of the research can be ascertained. Hence, no matter what methods are used, bibliometric analysis gives us a deep understanding of the structure, dynamics, and impact of scientific research. This understanding is useful for evaluating research, mapping knowledge, and making decisions.

Multiple studies have demonstrated the influence of employing bibliometric analysis in environmental research, which enhances comprehension of research patterns in environmental assessment through the examination of articles published over the past few decades (Ellili 2024; Li & Zhao 2015; Nita 2019). Environmental impact assessments are crucial to sustainable development and international conflict resolution, and these publications stressed the need for international cooperation and collaborative research in this area. Nita (2019) highlighted the necessity of overcoming political, economic, social, and technological challenges in order to encourage international scientific partnership. According to Li and Zhao (2015), there has been an increase in the number of internationally collaborated articles related to environmental issues over the past few years. This collaboration has resulted in more influential articles as ideas and workloads are shared. As a result, developing countries such as China, India, and Brazil have greatly benefited from this international cooperation. Li and Zhao (2015) also predicted that the prominent subjects of "biodiversity" and "climate change" in current environmental research will remain important in the future. So, to find out if the research trends are similar, the current study conducted a more thorough bibliometric analysis of EPI research rather than a bibliometric analysis of environmental sustainability overall.

This analysis succeeded in identifying the most recent advancements in studies related to EPI. These advancements include the annual scientific production, average citations received per year, and prominent research areas and journals that have published extensively on EPI studies. Furthermore, this analysis has also revealed the extent of collaboration diversity among countries and authors engaged in EPI studies. The comprehensive distribution of scientific findings, categorised by the author's country of origin, as well as the analysis of co-authors to

determine the extent of international collaboration, can provide valuable insights into potential avenues for enhancing such collaboration in the pursuit of environmental sustainability, as assessed by the EPI. As an added bonus, a summary of the most cited documents and research gaps can be identified with absolute certainty, especially documents that focus on the ranking of all countries. This document explored the implications and perspectives regarding the potential impact of the research pattern on the future of EPI.

The bibliometric analysis for this study was conducted using Bibliometrix (Derviş 2019) from R package and VOSviewer, while the clustering analysis was performed using Carrot2 Workbench. The Carrot2 Workbench tool was employed to identify clusters of topics that are associated with the EPI. Carrot2 is a widely recognised open-source search engine that is primarily acclaimed for its clustering functionality in organising web search outcomes. This component encompasses the implementation of various search result clustering algorithms, including K-means, Suffix Tree Clustering (STC), and Lingo. In this study, the initial step involved the selection of the Scopus database through a search for documents containing the keyword "Environmental Performance Index." The bibliometric analysis encompassed a total of 393 documents, spanning the time frame from 1994 to 2022. Following the extraction of the data, it was subsequently exported to Excel Common Separated Value (CSV) format and later uploaded to Biblioshiny, VOSviewer, and Carrot2 Workbench.

Bibliometric analysis provides insights into research trends and productivity; however, its limitations, including biases in citation counts, dependence on specific databases, and potential misinterpretation of metrics, should be considered when assessing research impact. Bibliometric databases frequently exhibit a bias towards English-language publications, which may lead to an underrepresentation of research conducted in other languages. Citations may serve multiple purposes, not all of which indicate the quality or impact of the referenced work. This involves recognizing prior research, substantiating assertions, or challenging the work of others. Additionally, widely used tools like Web of Science and Scopus offer a specific perspective on the bibliographic landscape; however, they exhibit limited coverage in certain disciplines, formats (e.g., books, conference papers), and geographic areas. Not all research outputs are included in these databases, resulting in incomplete data. Moreover, metrics such as the h-index or impact factor do not inherently assess the quality of research; instead, they reflect its visibility or popularity. Excessive focus on specific metrics may result in a restricted view of a limited number of publications or authors, which could distort the understanding of research impact.

4. Results and Discussion

4.1. A bibliometric analysis of recent developments in EPI studies

The main information can be found in Table 1 of the Scopus database, which contains 393 works published by 265 different sources between 1994 and 2022. The number of EPI-related documents published over the past decades shows a slow and steady increasing trend, with a compound annual growth rate of 11.39% (Figure 2). Furthermore, the rising number of EPI-related documents published demonstrates that environmental sustainability has prompted researchers to focus on the environmental problems such as increasing in global greenhouse gas emissions, water pollution, air pollution, plastic pollution and poor governance. The objectives of sustainable development, environmental health improvement, climate change

mitigation, and ecosystem vitality maintenance have propelled EPI to the forefront of international attention (Wolf *et al.* 2022).

Table 1: Primary data from the Scopus database for keyword with “Environmental Performance Index”

Description	Results	Description	Results
Main Information About Data		Authors Collaboration	
Timespan	1994:2022	Single-Authored Docs	64
Sources (Journals, Books, etc)	265	Co-Authors Per Docs	3.13
Documents	393	International Co-Authorships %	20.61
Annual Growth Rate %	11.39	Document Types	
Document Average Age	6.48	Article	307
Average Citations Per Doc	18.62	Book Chapter	28
Document Contents		Conference Paper	43
Keywords Plus (ID)	1834	Conference Review	1
Author’s Keywords (DE)	1148	Editorial	1
Authors		Letter	2
Authors	1094	Note	1
Authors of Single-Authored Docs	60	Review	10

The document's contents are also displayed in Table 1 via an indicator called Keywords Plus (ID), which signifies the sum of all keywords found in the article's title. The total number of documents in Keywords Plus for this discovery was 1834, which was over fourfold the number of documents. The average number of co-authors per document was 3.13, indicating that there were more than two authors on most of the documents, and the percentage of international co-authorships was 20.61%. The phrase "international co-authorship" refers to the writing of scientific articles by two or more authors from various nations. The higher the percentage of international co-authors, the more evidence there was of the importance of collaboration for broadening researchers' access to relevant data (OECD 2009). Many fields already practise having multiple authors on a paper, and it is found to have many advantages, including the following: 1) making research more enjoyable, efficient, and productive; 2) allowing researchers to generate more ideas, expand their methodological toolkit, and divide up the work; and 3) increasing the credibility of the papers' findings by providing additional supporting expertise from different researchers. Khor and Yu (2016) showed that, based on the Leiden Ranking data, when the international co-authorship ratio went up, so did the mean geographical collaboration distance (MGCD), which is a sign of more international co-authorship, and young institutions had a higher citation per year (CPP) increment than an MGCD increment. Even though international co-authorship increased the institution's field-weighted citation impact (FWCI), there was room for improvement in how much young institutions worked with well-known older ones (Khor & Yu 2016). Considering that environmental pollution is a worldwide problem, more international cooperation between countries is possible in the future, particularly within the same region, since this only accounts for 20% of current international collaboration. Therefore, it is possible to draw the conclusion that this finding supports Nita's (2019) assertion about the significance of collaborative research in assessing environmental impacts for sustainable development and international conflict resolution.

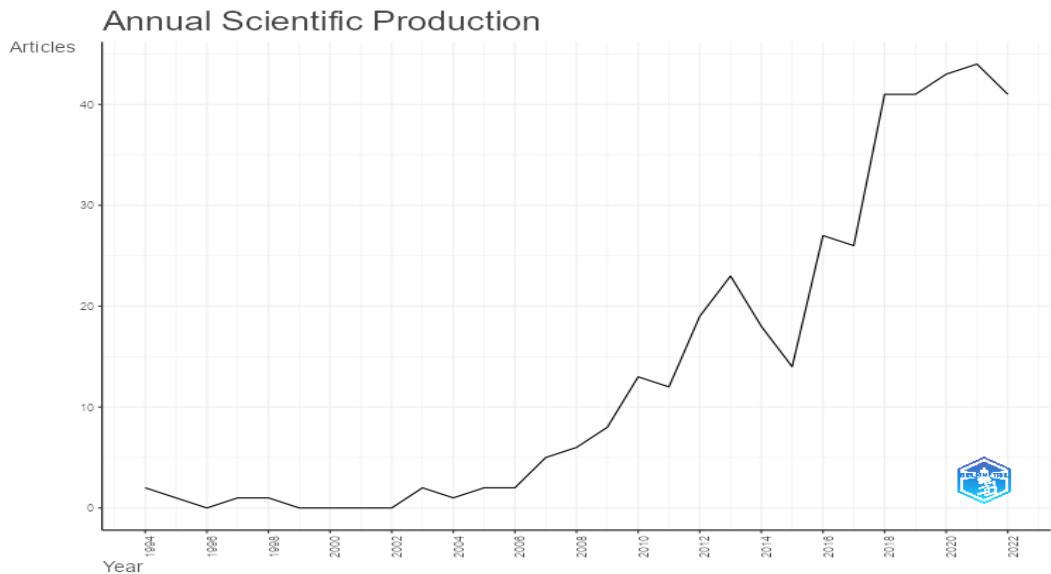


Figure 2: Annual scientific production for the key phrase "Environmental Performance Index" (1994 – 2022)

Although there was a slow upward trend in the number of related publications between 1994 and 2022, the average citations per year for a single document showed an opposite trend, with 2004 recording the highest average citations per year at 15.4 (Figure 3). The reason for a sharp spike in average citations for the year 2004 is because Färe *et al.* (2004) published a single article in that year that received many citations. In addition, that article served as the catalyst for other researchers to undertake similar investigations by introducing the concept of measuring environmental performance using DEA techniques. The average citations dropped significantly after 2004, with inconsistent trends owing to an increase in the number of work publications (as shown in Figure 2), causing the average citations per year for a single document to decrease. The assumption that researchers outside of the field of this study did not fully understand the significance of EPI in assessing a country's environmental performance contributed to the lack of citations. Hence, further efforts are required to engage the curiosity of people beyond the field of sustainable development research, encouraging their interests to dive deeper into the subject matter of the EPI.

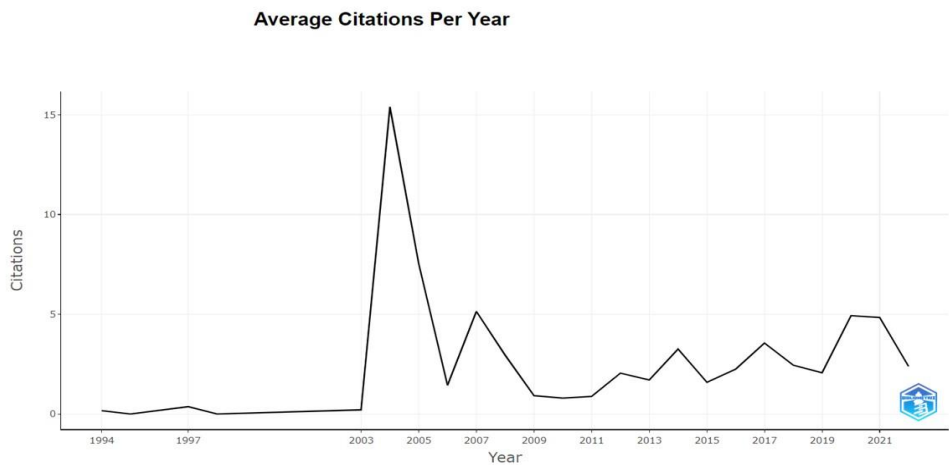


Figure 3: Average citation per year based on all EPI-related documents (1994 – 2022)

Table 2 shows the results of the bibliometric analysis broken down by the top 20 subject areas, which were determined by the Scopus research areas that included the keyword. Based on the rankings, it was found that environmental science had the most articles (210), followed by social sciences (116), energy (81), and engineering (76). Keep in mind that a single document may address several categories, making the total document count greater than 393. Surprisingly, the ability of environmental performance to collaborate with mathematical models, data analysis and security, algorithms, and computational theory was reflected in the rankings of computer science (7th) and mathematics (11th).

The Environmental Performance Index's top ten journal which published most articles related to EPI are listed in Table 3, along with the journals' h-index, g-index, m-index, and total citations. During 1994–2022, Sustainability (Switzerland) had the greatest number of publications (22), followed by the Journal of Cleaner Production (13), Ecological Indicators (12), Environmental Science and Pollution Research (8). Furthermore, Sustainability (Switzerland) was found to be the most influential journal worldwide according to the bibliometric analysis, with the highest h-index (11) and g-index (19), as well as an above-average m-index (1.10) but fewer total citations. (386). It was determined that the Journal of Cleaner Production was the second most highly referenced journal after Sustainability (Switzerland), but the Journal of Cleaner Production had 440 in total citations which was more than Sustainability (Switzerland). The journal with the highest number of total citations (562) was Ecological Indicators, which ranked fourth among the most productive journals for publication. In addition, the journal with the highest m-index (1.4) was Environmental Science and Pollution Research, which ranked fifth despite having a low h-index, g-index, and total citations. Only a small fraction of the papers appeared in high-impact journals. Journal content analysis revealed that leading EPI studies mostly addressed and discussed practical as well as theoretical problems related to sustainable development and the management of the environment.

Table 2: The top 20 fields of study that have been associated with EPI research publications

Rank	Subject Areas	Number of Articles
1	Environmental Science	210
2	Social Sciences	116
3	Energy	81
4	Engineering	76
5	Economics, Econometrics and Finance	74
6	Business, Management and Accounting	73
7	Computer Science	43
8	Agricultural and Biological Sciences	33
9	Decision Sciences	26
10	Earth and Planetary Sciences	19
11	Mathematics	14
12	Medicine	13
13	Arts and Humanities	11
14	Multidisciplinary	10
15	Chemical Engineering	9
16	Psychology	8
17	Physics and Astronomy	5
18	Chemistry	5
19	Materials Science	4
20	Biochemistry, Genetics and Molecular Biology	4

Table 3: The top 10 most productive journals for publications with the keyword "Environmental Performance Index"

Rank	Sources	Number of Articles Published	H-index	G-index	M-index	Total Citations
1	Sustainability (Switzerland)	22	11	19	1.10	386
2	Journal of Cleaner Production	13	10	13	0.77	440
3	Ecological Indicators	12	9	12	0.75	562
4	Environmental Science and Pollution Research	8	7	8	1.4	353
5	Ecological Economics	6	6	6	0.35	374
6	Sustainable Development	6	6	6	0.55	266
7	Advanced Materials Research	5	1	1	0.08	5
8	Journal of Environmental Management	5	5	5	0.26	390
9	Advances in Environmental Biology	4	2	3	0.15	9
10	Environmental Science and Policy	4	4	4	0.24	90

Figure 4 displays the cumulative top six most productive journals for publication output over time. The plot depicted a rise in the number of journals that cover the subject and related topics exceptionally well. The number of articles published on this subject by Sustainability (Switzerland) increased dramatically between 2019 and 2022, indicating that the journal was giving serious consideration to the significance of sustainable development especially in environmental problems. Sustainability (Switzerland) is a scholarly association that operates on an international scale and gathers from various disciplines. Its primary focus is on studying topics related to sustainable development and sustainability, encompassing economic, social, cultural, and environmental. The objective is to encourage scientific projections and evaluations of the impact of worldwide change and development by motivating researchers to share their theoretical and experimental findings in the fields of natural science, social science, and the humanities. The vast majority of the articles that were published in this journal concentrated on China and focused on achieving zero carbon emissions, developing green environments for cities or populated areas, and implementing measures to reduce climate change. Accordingly, the important role of EPI in assisting a country, particularly China, in preserving sustainability in its most heavily populated regions and in producing the most greenhouse gas emissions explain why this journal publishes a great deal of articles pertaining to EPI research.

As shown in Figure 4, the total number of articles published in journals has been steadily rising since 2010. This is due to the fact that since 2010, the current research trends prioritise environmental concerns and the refinement of innovative strategies that place a greater emphasis on the interaction between humans and machines rather than the concept of sustainability and sustainable development as a whole (Jung & Kim 2023). Therefore, EPI has been used by the majority of countries as a tool to determine whether or not they have improved environmental sustainability while also developing effective technology to improve the quality of human life. This means that EPI research could grow in the coming years, and it is an encouraging indication that researchers know how important it is for all countries to meet the Sustainable Development Goals for 2030 by fully understanding the importance of EPI, which can help promote long-term growth in sustainability.

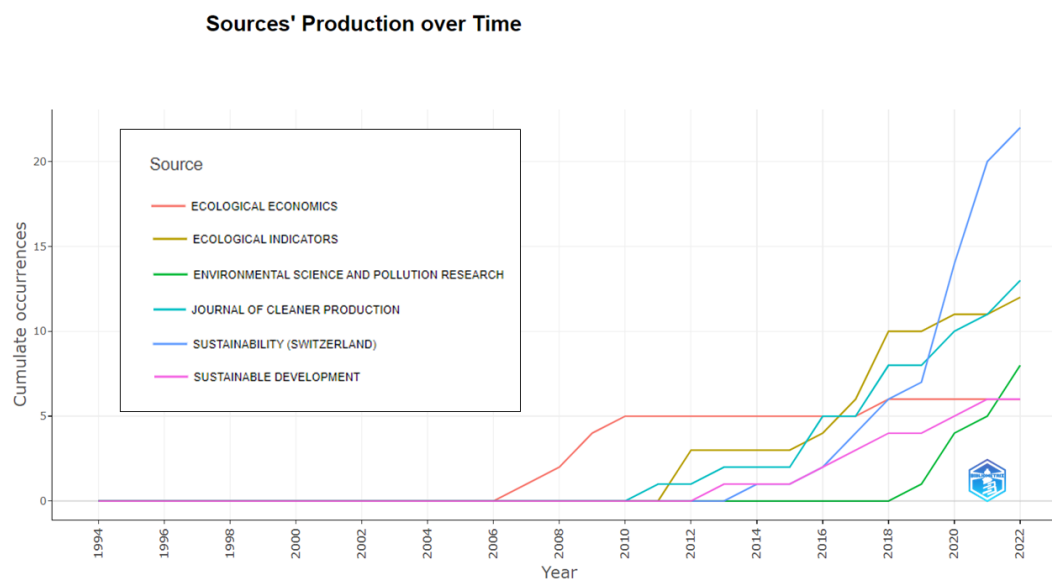


Figure 4: The cumulative top 6 most productive journals for publication output over time (1994 – 2022)

4.2. The diversity of countries and authors involved in EPI collaborations

Keep in mind that, according to Table 1, there were 1094 authors who contributed to the creation of 393 documents for 265 publications over the course of the past decades. In order to determine the total number of documents produced by each nation between 1994 and 2022, it was necessary to look into the country of author's affiliation. Figure 5 depicts the top 24 countries in terms of the total number of scientific publications, broken down by the author's country of affiliation. The map presented in Figure 5 displays varying shades of blue, with darker blue indicating higher scientific production, lighter blue indicating lower scientific production, and grey indicating that there was no scientific production for that country.

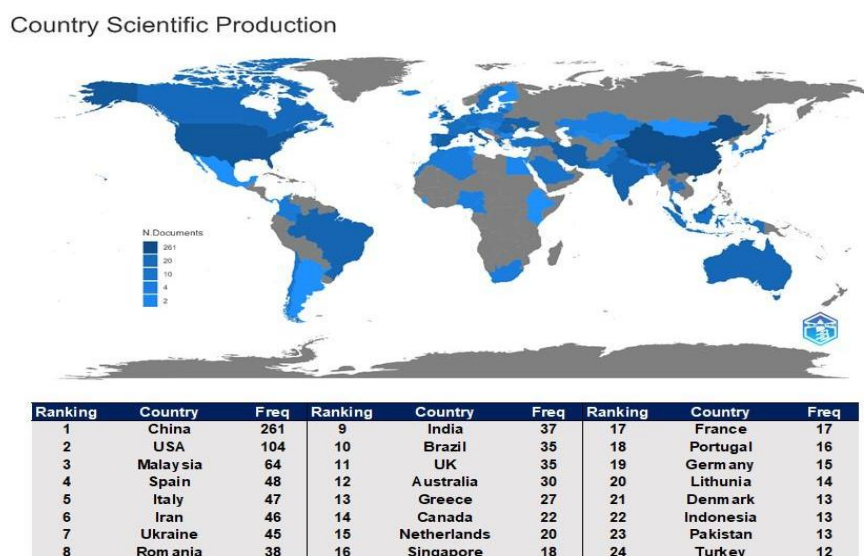


Figure 5: Top 24 for distribution of scientific output by country of origin of authors (1994 – 2022)

Authors from China produced the most publications related to EPI studies, with 261 in total, followed by authors from the United States of America (USA), which produced the second most, with 104 total. Surprisingly, Malaysia, a small developing country, was listed as the third country with the most publications, with 64 documents. India was ranked ninth on the list with 37 documents, which was also an intriguing finding. Indian experts and governments noted that some indicators from the latest EPI 2022 report were extrapolated and based on unscientific methods (Roy 2022). Nevertheless, the country has yet to release an in-depth investigation or scientific resolution to address the issue. Given that a single production can have multiple authors from the same country or different countries for collaboration in EPI research, the total number of affiliations by country will exceed the total number of documents (393) that should be produced. Thus, it is reasonable to assume that the number of documents presented for each country corresponds to the number of authors who have contributed to the country's production over the past decades.

Numerous researchers, particularly from China and the United States, had a keen interest in EPI research, demonstrating how crucial it was for nations to achieve environmental sustainability. East Asia and North America accounted for 40% of global greenhouse gas emissions in 2018, with China and the United States dominating emissions within their respective regions (Lamb *et al.* 2021). More than a quarter of annual global greenhouse gas emissions were produced by these two countries, contributing to climate change. As part of the Paris Agreement (United Nations n.d.), China and the United State were committed to reduce emissions by decreasing its reliance on coal and increasing its use of renewable energy. According to Maizland (2021), the Chinese government facing discontent from their people rooted from air pollution, limited water supplies, and contamination of the soil, which threatens their health and livelihoods.

According to the outcome of previous global EPI reports, Malaysia was ranked in the 9th position in 2006, the 26th position in 2008, the 54th position in 2010, the 25th position in 2012, the 51st position in 2014, the 63rd position in 2016, the 75th position in 2018, the 68th position in 2020, and the 130th position in 2022. Malaysia's performance on the global EPI plummeted from 9th in 2006 to 130th in 2022, drawing the attention and concern of the government and authorities. The significant ranking disparity over the past few decades can be traced back to the major environmental issue categories of air and water pollution, waste management, and climate change. These concerns helped enhance policymaking decisions by incorporating awareness of the environment and practises for productivity into Malaysian culture (Mei *et al.* 2016). This included the recognition of the significance of conserving biodiversity, forestry and wildlife restoration, and soil conservation for the future (Mei *et al.* 2016).

Undoubtedly, the consequences of climate change are not solely limited to Europe, the third most populous continent worldwide. Air pollution, droughts, wildfires, and rising sea levels are just a few of the problems that impact every country in the region. According to Igini (2022), countries such as Italy and Spain have a natural tendency to have hot and dry summers, and as temperatures continue to rise, the seasons will get progressively hotter and drier. Water supplies are profoundly impacted by recurrent droughts, which result in failed crops, an increased risk of wildfires in poorly managed regions, and a deterioration of public health conditions in cities and areas impacted by heatwaves (Igini 2022). On the other hand, according to Kaleji (2023), there have been reports indicating that the water level of the Caspian Sea has dropped by one meter in the past few years and might drop by nine to eighteen meters (about thirty-five feet) before the end of this century. A country such as Iran has a long history of working together

with Russia in order to make attempts to preserve it. The principal cause of the decline in water level in the Caspian Sea is climate change, which includes higher temperatures, less precipitation, and increased evaporation (Moussavi 2023). For this reason, several European countries, especially Italy and Spain, as well as Iran, are devoting significant resources to improving their environmental performance and publishing extensively on the subject.

In academic world, what matters most is the impact of those articles on society and the world, as well as their ability to inspire other researchers to conduct in-depth research on a particular topic. Table 4 shows the total number of citations and the average number of citations for the top 25 countries. Articles from the authors based in United States came in second with 954 total citations but had a higher average article citation of 30.77 than authors from China, which had the most total citations (1,320) and an average article citation of 20.00. Even though Germany was ranked 19th for total scientific production according to the data presented in Figure 4, but it received the third-highest number of total citations (480), with a higher average article citation of 96.00. Similar to Singapore, whose articles had a greater impact than those of Malaysia, despite Singapore's lower scientific output. In fact, Malaysia was ranked 21st for having the most total citations (75), but its average article citations were only 4.69.

Table 4: The top 25 most cited countries for publications with the term "Environmental Performance Index"

Ranking	Country	Total Citations	Average Article Citations	Ranking	Country	Total Citations	Average Article Citations
1	China	1320	20.00	14	Brazil	149	14.90
2	USA	954	30.77	15	Lithuania	115	28.75
3	Germany	480	96.00	16	Netherlands	114	22.80
4	Singapore	412	103.00	17	Greece	108	10.80
5	Italy	375	41.67	18	Iran	108	10.80
6	UK	312	39.00	19	Portugal	95	19.00
7	Spain	274	21.08	20	Belgium	85	21.25
8	Finland	185	185.00	21	Malaysia	75	4.69
9	Australia	184	30.67	22	Bangladesh	73	36.50
10	India	183	15.25	23	Turkey	72	24.00
11	France	182	182.00	24	Japan	61	30.50
12	Canada	175	35.00	25	Cyprus	44	44.00
13	Romania	152	16.89				

One of the most unexpected developments of the 21st century was China's meteoric rise to the top of scientific research, resulting in far-reaching consequences in a world where information continues to be viewed as "the one ring that rules them all." (Xie & Freeman 2019). There is no denying China's impressive output of high-quality publications over the past few decades, especially in the field of EPI-related research. Articles produced by China's authors increased in the number of citations because of two reasons: the fast growth of papers written by Chinese researchers and the fact that the scientific quality of Chinese papers was better than the average paper in Scopus (Xie & Freeman 2019). Due to the high quality of Chinese research, the number of citations from "authors abroad" to Chinese-addressed papers increased by 50 percent (Xie & Freeman, 2019). The extent and quality of research, as well as library subscription practises, were also significantly impacted by the amount of money countries allocated to the scientific enterprise (Gomez *et al.* 2022). This means that any country with such advantages would be likely to receive more citations for its research.

On the other hand, this is not the only factor that determines whether a country will get higher citation. Keep in mind that despite contributing fewer articles, Germany and Singapore ranked higher in total citations than most other countries. One of the reasons for the rise in citation concentration was that the career paths of scientists were changing. More and more scientists were joining research projects led by others instead of starting their own long-term, publication-active research careers (Nielsen & Andersen 2021). In other words, the global percentage of "transient scientists," whose careers in academic science are short and who produce few scholarly works, is on the rise. Aside from that, the higher international co-authorships shown in Table 1 indicated that researchers collaborated with more countries than in the past, resulting in a rise in the total number of citations for given research. Authors with a high number of citations had a greater chance of receiving funding, which allowed them to build out their research facilities and increase their network of co-authors, which in turn led to more publications and citations (Nielsen & Andersen 2021).

Collaborations between scientists from different countries improved the quality of research, which led to a big rise in the number of articles written and the total number of citations. Figure 6 shows the geographic breakdown of the countries involved in order to draw conclusions about the nature of the partnerships existing between them. In VOSviewer, a thicker line indicates a stronger connection between two countries, and a closer proximity between them indicates a closer relationship. Variations in the size of the circle indicate that the larger the circle, the greater the number of documents published from that country. The clusters are shown by the different colours in Figure 6, and there are nine clusters for this analysis. For instance, the United States, Australia, and India belong to the same cluster, which is denoted by a brown circle. This study solely focused on the degree of collaboration among countries in EPI research. However, it did not extensively examine the significance and interpretation of each of the nine clusters.

Co-authorship analysis can be used to identify collaborations between countries on research related to EPI. The results of the co-authorship study showed that researchers from China had the most links to other countries, followed by the USA, Italy, Romania, Australia, and Greece as shown in Table 5. It was found that there were several influential relationships and associations between China and Pakistan, with a total of 7 links; China and the United States of America, with a total of 6 links; and China and Australia, with a total of 5 links. The same chart also revealed some fascinating partnerships, such as the unexpected connections between China and Malaysia and between Malaysia and Pakistan, and the single link between the United States of America and India or between India and Australia.

Over the past few years, countries have worked together to address environmental issues, particularly climate change, which would have been impossible for any one country to deal with alone. For instance, the collaboration between China and Pakistan was primarily due to the China–Pakistan Economic Corridor (CPEC), which was established for the benefit of communities in the region and the economic development of both nations and thus involves numerous projects. A study by Saad *et al.* (2019) found that citizens' perceptions of environmental protection in areas such as air quality, noise, climate change, and waste management were not satisfactory after CPEC projects had a significant impact on the environment. As a result, the governments of China and Pakistan have been prioritising environmental protection and green initiatives in an effort to make life in the neighbouring regions more pleasant by lowering pollution levels (Saad *et al.* 2019). Next, China and the U.S. collaborated, mainly because China and the U.S. were the world's two biggest emitters of

greenhouse gases, so any effort to solve the climate crisis had to include big cuts in emissions from these two powerhouse nations. The only way for global efforts to stop climate change to be successful is for both countries to work together and make a full commitment to reaching a net-zero emissions peak by 2030.

International collaborations have significantly influenced the development of the EPI as an effective instrument for evaluating and directing global environmental policy. The collaborations have improved the methodological rigor of the EPI, aligned it with global sustainability objectives, and enabled cross-country comparisons. As environmental challenges evolve, international collaborations will be essential for maintaining the relevance and effectiveness of the EPI in supporting global sustainable development, particularly in addressing emerging issues such as circular economy practices, sustainable consumption patterns, and climate resilience.

Table 5: The topmost links show that a country collaborated with other countries for EPI research

Country	Number of links
China	32
USA	29
Italy	27
Romania	25
Australia	24
Greece	21

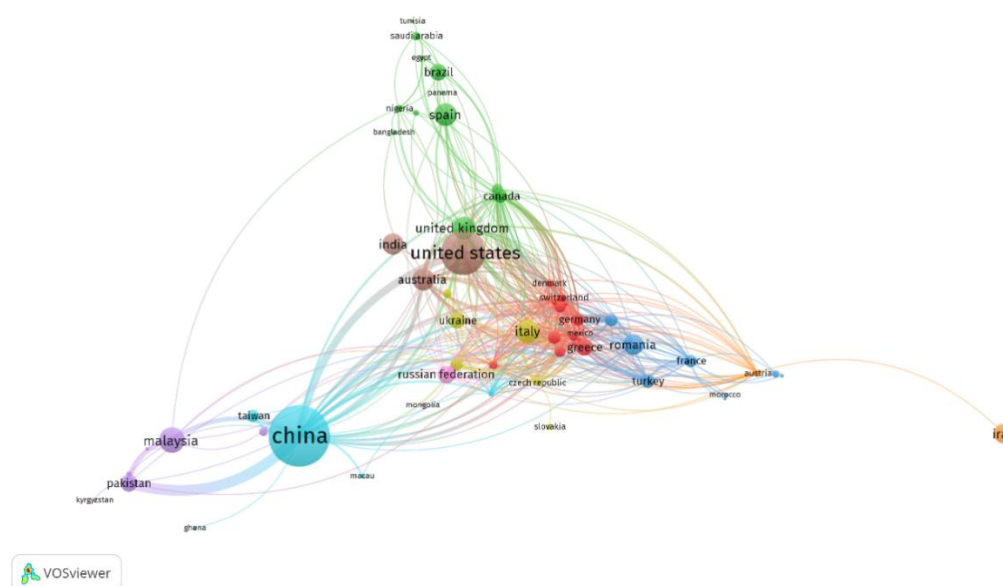


Figure 6: The distribution of international collaboration based on co-authorship analysis

4.3. An overview of the most-cited documents and the observation of findings regarding the EPI

4.3.1 General EPI research

Documents with the highest number of citations provide valuable insight into which areas of study have had the greatest impact on the field. Table 6 shows the 10 most-cited documents related to EPI research from 1994 to 2022. Each of the most-cited documents was reviewed in order to find out what kind of research had been conducted in the prior studies.

The top two studies both discussed and investigated the application of Data Envelopment Analysis (DEA) to the evaluation of environmental performance. The research carried out by Färe *et al.* (2004) was the first of its kind to propose a method for measuring environmental performance using DEA techniques (2nd place, 303 citations). The method generated an environmental performance index number that quantifies the ratio of good to bad output. This is achieved by increasing good outputs and reducing bad outputs without triggering the disposal of bad outputs. The proposed index provided a valuable tool for assessing the environmental performance of firms, industries, and countries. It enables a comparison of their performance with that of their competitors, allowing for the identification of areas in need of improvement. However, the proposed index solely focused on the ratio of good output to bad output, neglecting crucial environmental factors like biodiversity, ecosystem services, and climate change. Thus, Zhou *et al.* (2007) introduced a non-radial DEA method for evaluating environmental performance. This approach offered a more precise and comprehensive assessment compared to conventional radial DEA models. The paper has achieved significant recognition with 372 citations and is ranked first in its field. The method comprised two components: a non-radial DEA-based model for comparing environmental performance across multiple regions and a non-radial Malmquist environmental performance index for monitoring environmental performance over time. The application of this method to a case study of Organisation for Economic Co-operation and Development (OECD) countries revealed an improvement in environmental performance from 1995 to 1997. The proposed non-radial DEA method was limited in its applicability to environmental performance measurement issues. This is because existing DEA-based models for environmental performance measurement typically use radial efficiency measures, which may not be preferred by decision-makers or environmental analysts due to their weaker discriminating power and considerations of realism, economy, and politics.

The third-ranked article examined the impact of corporate sustainability strategies on the correlation between environmental and economic performance in Europe's paper manufacturing sector. The study found that firms with pollution prevention-focused strategies had a more favourable relationship between environmental and economic performance, making improvements in corporate sustainability more probable (Wagner 2005). It should be noted that the findings of their study may lack generalizability beyond Europe or other industries. The positive aspect of their discovery is that the environment and economy are interconnected and must be mutually supported for a nation's development. Countries with favourable climates and lower levels of environmental pollution are more likely to attract investments from abroad, which can significantly stimulate a nation's economy. Therefore, firms can transition to an economy based on sustainability by decreasing their reliance on fossil fuels and adopting green energy sources, resulting in a reduction of harmful gas emissions into the atmosphere.

The fourth-placed article gave a framework for analysing the changing environmental performance of countries using EPI based on frontier efficiency techniques and a Malmquist index approach. The method enabled the dissection of changes in overall environmental performance into variations in relative eco-efficiency and shifts in environmental technology (Kortelainen 2008). However, this study had some limitations, including the fact that the choice of pollutants and environmental pressure indicators affected the results. The varying environmental impacts of different pollutants and indicators, as well as their relevance in different contexts, contribute to this situation. If the analysis solely considers greenhouse gas emissions, it might fail to consider other significant environmental pressures like water pollution or air pollution. Differences in weights or measures assigned to various pollutants or indicators can result in varying conclusions regarding the comparative environmental performance of different countries or regions. Hence, it is crucial to thoroughly evaluate the selection of pollutants and indicators and to employ scientifically accurate and transparent methods for their selection and weighting.

Table 6: The top 10 most-cited EPI research documents over the past decades

Rank	Title	Authors	Journal	Year	Country	Total Citations	TC per Year	Normalized TC
1	A Non-Radial DEA Approach to Measuring Environmental Performance	Zhou, P., Poh, K.L., Ang, B.W.	European Journal of Operational Research	2007	Singapore	372	21.88	4.37
2	Environmental Performance: An Index Number Approach	Färe, R., Grosskopf, S., Hernandez-Sancho, F.	Resource and Energy Economics	2004	USA Spain	303	15.15	1.00
3	How To Reconcile Environmental and Economic Performance to Improve Corporate Sustainability: Corporate Environmental Strategies in The European Paper Industry	Wagner, M.	Journal of Environmental Management	2005	Germany	270	14.21	1.94
4	Dynamic Environmental Performance Analysis: A Malmquist Index Approach	Kortelainen, M.	Ecological Economics	2008	Finland	180	11.25	3.90
5	Aquaculture At the Crossroads of Global Warming and Antimicrobial Resistance	Reverter, M., Sarter, S., Caruso, D., Avarre, J.-C., Combe, M., Pepey, E., Pouyaud, L., Vega-Heredía, S., de Verdal, H., Gozlan, R.E.	Nature Communications	2020	France Germany	155	38.75	8.65

Table 6 (Continued)

6	Trilemma Assessment of Energy Intensity, Efficiency, And Environmental Index: Evidence from BRICS Countries	Baloch, Z.A., Tan, Q., Iqbal, N., Mohsin, M., Abbas, Q., Iqbal, W., Chaudhry, I.S.	Environmental Science and Pollution Research	2020	China UK Pakistan	136	34.00	7.59
7	Assessment Of the Economic, Social and Environmental Dimensions of The Indicators for Sustainable Development	Strezov, V., Evans, A., Evans, T.J.	Sustainable Development	2017	Australia	130	18.57	5.48
8	A Global Water Quality Index and Hot-Deck Imputation of Missing Data	Srebotnjak, T., Carr, G., De Sherbinin, A., Rickwood, C.	Ecological Indicators	2012	Germany India Canada USA	129	10.75	5.35
9	Assessing Urban Sustainability of Chinese Megacities: 35 Years After the Economic Reform and Open-Door Policy	Huang, L., Yan, L., Wu, J.	Landscape and Urban Planning	2016	China USA	102	12.75	5.90
10	Relationship Between Urbanization and CO2 Emissions Depends on Income Level and Policy	Ponce De Leon Barido, D., Marshall, J.D.	Environmental Science and Technology	2014	USA	101	10.10	3.21

The study by Reverter *et al.* (2020) provided important insights into the relationship between climate change, aquaculture, and antimicrobial resistance (AMR). The research sheds light on the potential environmental and human health consequences resulting from these factors. This study holds the 5th position in terms of total citations, indicating its impact and relevance in the scientific community. The paper used the EPI as a metric to examine the intricate relationship between global warming and the prevalence of AMR in aquaculture. The paper's high citation count can be attributed to its significant impact on the field of environmental health. It effectively emphasised the importance of adopting a sustainable approach to food production, specifically in relation to the potential risks associated with antibiotic use in aquaculture. The challenge of feeding a rapidly growing human population while minimising the environmental impact of food production, particularly in low- and middle-income countries, is a significant issue that requires substantial efforts and strategic solutions. According to their study, a potential solution to address the need for protein that would benefit both human and environmental health is to shift the human diet towards higher consumption of fish and seafood.

Baloch *et al.* (2020) conducted a comprehensive assessment of the energy intensity, efficiency, and environmental performance of the BRICS countries (6th place, 136 citations). The study employed mathematical models and econometric techniques to develop a novel environmental index for the BRICS countries. The index was constructed using available data from 2011 to 2016. The study's findings indicated that Brazil and Russia exhibited the highest environmental index values, whereas India had the lowest. The study's findings were influenced

by the mathematical models and econometric techniques employed, which were not adequately considered despite their significance in assessing environmental performance, as well as factors such as population growth, economic development, and technological advancements. Hence, it is advisable to proceed with caution when interpreting the findings of the study, and additional research is necessary to gain a comprehensive understanding of the environmental performance of the BRICS nations.

The seventh-placed article compared nine different ways to measure sustainable development, such as the Change in Wealth Index (CWI), Ecological Footprint (EF), Environmental Performance Index (EPI), Environmental Sustainability Index (ESI), Genuine Savings Index (GSI), Global Well-Being Index (GWI), Happy Planet Index (HPI), Human Development Index (HDI), and Sustainable Society Index (SSI), and proposed a normalised average sustainability index (NASI) that took all of these things into account. In their study, the countries with the highest NASI scores were Switzerland, Norway, and Sweden, while the countries with the lowest NASI scores were Burundi, Sierra Leone, and Niger (Strezov *et al.* 2017). The future relevance of NASI is uncertain due to factors such as the adoption of sustainable development policies, changes in global economic and environmental conditions, and the emergence of new indices for measuring sustainable development. Although NASI may retain its utility as a measure of sustainable development in the future, it is dependent upon regular updates and refinements informed by current data and research.

The eighth article examined the use of the Water Quality Index (WATQI) as a water quality indicator in the 2008 EPI report. The WATQI was developed by Srebotnjak *et al.* (2012), who provided an explanation of its rationale and methodology and showed how hot-deck imputation of missing values can increase its geographic coverage and better inform decision-makers on the nature and scope of water quality issues in a time of scarce globally comparable water quality monitoring data. The WATQI enables the nation to evaluate freshwater resources and discover best practices for effective management. Therefore, it is necessary to conduct additional research and allocate resources to address the significant deficiency in global environmental monitoring. This can be achieved by creating a universally comparable composite measure of water quality in the future.

Huang *et al.* (2016) analysed the growth of and its impact on China's megacities from an environmental standpoint (9th place, 102 citations). It brought attention to the fact that although human well-being had improved significantly, environmental issues and economic inequality were on the rise. However, this study's limitations included the use of aggregated data, which did not fully capture the complexity of individual cities, and its narrow focus on only ten megacities in China, which was not representative of all Chinese cities. The tenth-placed article looked at how urbanisation and environmental policy affected CO₂ emissions in 80 countries between 1983 and 2005. Ponce De Leon Barido and Marshall (2014) found that the relationship between urbanisation and emissions depends on a country's environmental policy, with stronger policies making the effects of urbanisation on emissions less bad. However, the study did not take into account the most recent developments in urbanisation and environmental policy, as it only covered the years 1983–2005.

In summary, the top 10 highly cited papers demonstrated the significance of environmental indices as valuable tools for assessing the environmental progress of nations as well as determining areas that require improvement. The index developed by Färe *et al.* (2004) has inspired other researchers to further develop more accurate and easily implementable methods for evaluating the environmental performance of countries. Scientific research on EPI studies

has shown a noticeable increase since 2010, indicating a growing trend among organizations to adopt sustainable and environmentally friendly practices. Several factors contribute to this trend, including increased environmental consciousness in business practices and the advent of new technologies aimed at reducing environmental footprints. The future direction of the EPI will reportedly prioritize climate change due to the increasing prominence of advanced technologies in the development process. As humans rely on these technologies to enhance their quality of life, the resulting instability in climate patterns necessitates a greater focus on addressing climate change. The introduction of a new indicator in the 2020 EPI report assesses countries' progress towards achieving zero emissions of four greenhouse gases by 2050. This addition has prompted researchers to prioritize the investigation of EPI studies related to climate change issues. Additional indicators will be incorporated into the calculation of the EPI, enhancing its reliability and ensuring its alignment with current and forthcoming policies. This will result in mutual advantages for businesses and the environment, fostering the development of a sustainable future for all parties involved. However, relying solely on the index is insufficient to guarantee the long-term sustainability of the environment. Hence, countries should also pledge to enhance their environmental policies and practices, and the attainment of a sustainable future is contingent upon this condition.

The majority of the topmost-cited documents for this EPI research study focused on a novel approach to measuring environmental performance across a variety of domains, along with the difficulties of doing so and the consequences for those involved, communities, and nations. Some approaches, for example, were not well-suited to dealing with the issues, and the selection of indicators often failed to take into account crucial factors such as air and water quality, waste management, and ecosystem protection that influenced the outcomes. Furthermore, these studies still do not provide enough information to fully understand how to resolve the problems with EPI research, especially when it comes to missing data and inconsistent methods that are connected to three main policy goals: improving environmental health, protecting ecosystem vitality, and mitigating climate change. These results will make it easier for researchers to get involved in existing EPI research in a deeper way, especially when it comes to using statistical methods to deal with missing data, which is a key part of making EPI findings more useful.

4.3.2 EPI ranking research

This paper seeks to find any findings or criticisms from relevant articles that relate to the measurement of the EPI, and how these factors influenced the ranking for all countries. Therefore, document clustering was accomplished by automatically classifying documents based on the similarities in their contents. The objective is to automatically learn the category of each document and then create clusters that are similar internally but significantly distinct from one another. Figure 6 shows the results of clustering documents in Carrot2 Workbench using the K-means algorithm. After the classification process was complete, 25 clusters were established, and relevant documents were assigned to each. For instance, in an EPI study cluster labelled "Energy, Economic, Consumption," 23 documents were found to contain common terms related to energy, economics, and consumption. Each document's abstract was used in the clustering process to determine which topics were most central to that particular document. Only 21 documents were clustered as "Countries, EPI, Ranking" out of all EPI research documents (on the top right side of Figure 7). This cluster is the most important cluster for this study, as it relates to how the EPI was used to rank countries, and these 21 documents can demonstrate some interesting findings that can provide additional insight.

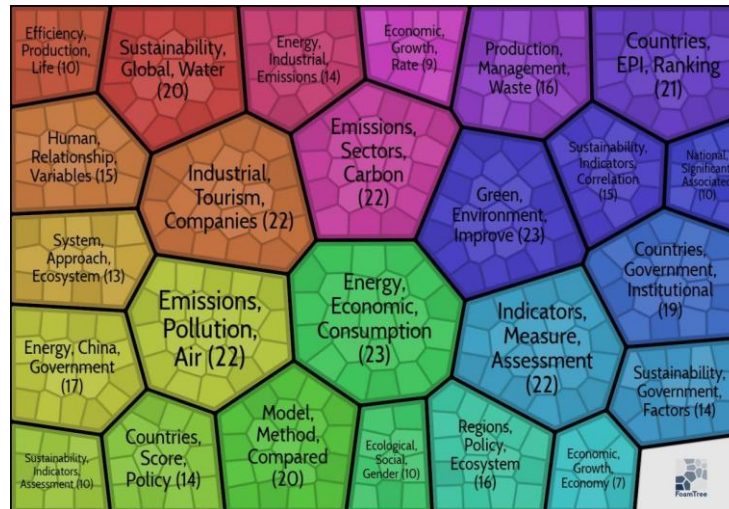


Figure 7: Clustering documents for EPI research with the K-mean algorithm in Carrot2 Workbench

An analysis of the most-cited papers in the cluster "Countries, EPI, Ranking" revealed some fascinating insights into the approaches taken to the issues of ranking in EPI. Table 7 presents the five most-cited documents pertaining to the cluster "Countries, EPI, Ranking" between 1994 and 2022. Surprisingly, a study by Färe *et al.* (2006) received 27 citations in the cluster "Countries, EPI, Ranking," placing it in second place. The study pioneered the use of the EPI to compare the efficiency of businesses that make both positive and negative contributions to the environment. The EPI was developed with the aim of achieving desirable index number properties in accordance with production theory. The SO₂ emission regulations faced by the electric power industry were analysed using the EPI in their study. The authors showed how useful the EPI can be by analysing data from coal-fired power plants in the United States between 1985 and 1998. The research found that during 1994–1995, EPI at power plants with units in Phase I of the Acid Rain Programme significantly improved. Thus, the study becomes the foundation for all EPI research documents and can be applied to other industries and environmental regulations, as well as international comparisons and corporate social responsibility reporting.

The most cited document related to the cluster "Countries, EPI, Ranking" was by Foster *et al.* (2013), which examined the reliability of rankings obtained from composite indices that combined information from two or more components using a weighted sum. The authors analysed the Human Development Index (HDI), the Index of Economic Freedom (IEF), and the Environmental Performance Index (EPI) to evaluate the robustness of rankings derived from composite indices using the method proposed by Foster *et al.* (2010). The study discussed the theoretical connections between the prevalence of robust comparisons, Kendall's tau rank correlation coefficient, and statistical association across components and provided insights into the dependability of rankings obtained from composite indices. In addition, the implications of index component redundancy were analysed. However, the study does not provide a definitive ranking of the indices; rather, it assesses the dependability of rankings derived from composite indices. As a result, the study made a few recommendations for what should come next, such as studying the robustness of composite indices in terms of rank and creating appropriate robustness assessment methods.

Table 7: The top 5 most-cited EPI research papers pertain to the cluster "Countries, EPI, Ranking"

Rank	Title	Authors	Journal	Year	Country	Total Citations
1	Composite Indices: Rank Robustness, Statistical Association, and Redundancy	Foster, J.E., McGillivray, M., Seth, S.	Econometric Reviews	2013	USA Australia UK	66
2	Social Responsibility: U.S. Power Plants 1985-1998	Färe, R., Grosskopf, S., Pasurka Jr., C.A.	Journal of Productivity Analysis	2006	USA	27
3	The Sustainable Society Index: Its Reliability and Validity	Witulski, N., Dias, J.G.	Ecological Indicators	2020	Portugal	13
4	Assessing Global Environmental Sustainability Via an Unsupervised Clustering Framework	Kanmani, A.P., Obringer, R., Rachunok, B., Nateghi, R.	Sustainability (Switzerland)	2020	USA	10
5	Prioritizing Conservation for The Reduction of Gulf Hypoxia Using an Environmental Performance Index	Barnhart, B., Bostian, M., Whittaker, G., Grosskopf, S., Färe, R.	Ecological Indicators	2016	USA	7

The article ranked third that had the most citations examined the reliability and external validity of the Sustainable Society Index (SSI) for 154 developing and developed countries for the year 2016 (Witulski & Dias 2020). The study emphasised the need for a comprehensive statistical analysis and adjustment of the indices that represent sustainable development in order to achieve a theoretically and statistically reliable representation of the concept. For policymakers and researchers interested in measuring and promoting sustainable development, their findings were useful. There was no clear response to the question of whether or not the EPI provides a valid ranking in their findings. A high correlation was found between the two indices in 2014 and 2016 when the EPI was used to compare the SSI's country rankings on the environmental dimension. This indicated that the EPI was a viable method for ranking countries based on their environmental performance. Further research is necessary to determine the validity and dependability of the EPI scores used to rank countries.

The article that came in fourth place and proposed a novel data-driven framework to evaluate the environmental sustainability of countries in an objective manner by leveraging unsupervised learning theory was the most vital finding of research ever published (Kanmani *et al.* 2020). The framework employed a clustering method known as Self-Organized Maps (SOM) to classify countries based on their distinctive environmental performance metrics and to monitor their development in terms of shifts within clusters over time. The study assisted in addressing the gaps in traditional EPI frameworks that support sustainable development policies. Kanmani *et al.* (2020) also highlighted the inconsistencies in the EPI calculation that can lead to inaccurate depictions of the relative sustainability of countries over time. In addition, the study argued that the EPI ranking process was prone to bias because of the way in which environmental indicators were selected and weighted. However, future studies may investigate

alternative clustering methods for evaluating environmental sustainability and compare them to the proposed SOM framework.

A fifth-placed article that used the EPI to rank regions within the Mississippi/Atchafalaya River Basin based on their environmental performance, taking into account both agricultural productivity and nutrient loadings to the Gulf of Mexico, was also an interesting study (Barnhart *et al.* 2016). The EPI was used as a tool to help figure out where to focus agricultural conservation efforts across the whole MARB in order to reduce hypoxia in the Gulf and maintain food security through efficient farm production. Despite its use of the EPI to rank regions, the paper makes no attempt to address concerns about the index's lack of objectivity or impartiality. There is potential for EPI to be fashioned in a way that allows it to evaluate environmental performance on regional or state levels.

The findings presented in Figure 7 and the compilation of highly referenced documents outlined in Table 7 collectively demonstrated that certain materials possessed significant potential for addressing challenges within the framework of EPI. This is particularly relevant given the recent criticism surrounding the EPI's lack of consistency in its calculation methodologies. The presence of bias in the ranking of countries becomes evident when a new indicator is incorporated into the calculation of the EPI and an inconsistent weighting method is employed. The EPI scores and rankings may give rise to concerns among nations regarding their reliability. Hence, it is advisable for researchers to conduct investigations on addressing the issue of inconsistency in EPI calculations and weighting methods with the aim of enhancing the relevance and reliability of EPI in the coming decades.

5. Conclusion

As the world's population rises and human-driven environmental exploitation increases, the problem of environmental sustainability has become an urgent priority and a subject of intense discussion. The rising global participation in fossil fuel burning, extensive vehicle usage, and the illegal act of deforestation, all of which contribute to the release of greenhouse gases, is a prime illustration of this occurrence. The Environmental Performance Index (EPI) has been extensively used as an indicator of benchmarks because it provides a useful tool for policymakers, experts, authorities, and consumers to track and evaluate their country's performance in comparison to that of other nations about environmental sustainability.

The rapid rise in human-machine connections is indicative of the world's fast technological advancement toward a future in which people can live in more comfortable and convenient ways. Scientists and governments are already worried that rapid growth in technology will have a negative impact on the environment. Therefore, this is the reason why the number of scientific publications that are linked to EPI research has been expanding ever since 2010, despite the fact that the annual rate of growth in the number of published papers is smaller. One such piece of evidence for this is the frequency with which authors from different nations work together. Indications of the importance of collaboration in increasing researchers' exposure to relevant studies grew in proportion to the number of foreign collaborators. International cooperation is on the rise as governments see the value in pooling resources to address problems with far-reaching environmental consequences. For instance, China and the United States are cooperating to address their primary concerns over the production of greenhouse gases because both countries are the primary contributors to this issue. Scientists from different countries

working together can also improve the quality of research, which has led to a big rise in the number of papers written and the overall number of citations.

A large number of the most-cited papers showed the significance of EPI and provided a new method for assessing environmental performance in many fields. With the addition of a new indicator measuring whether nations are on pace to achieve zero emissions of four greenhouse gases by 2050, the focus of the EPI is going to shift in the future. Carbon dioxide, methane, fluorinated gases, and nitrous oxide are some of the gases that contribute to global warming. Several academics will give priority to the investigation of EPI studies related to climate change. Computer science and mathematics surprisingly ranked well on EPI's list of scientific productions, reflecting the ability of environmental performance to engage with mathematical models and computational theory. Research can thus go on to improve existing indices, such as the EPI, based on the results of this bibliometric study, with the ultimate goal of making the importance of environmental sustainability more widely understood.

Nonetheless, it is possible that certain biases or gaps in the bibliometric analysis for this study may have occurred; however, these did not significantly influence the findings. This was due to the study's objective of determining whether the scientific production, quality, and impact of EPI research continue to hold relevance within the academic community. Since bibliometric analysis relied on Scopus, it may not have covered all relevant publications, especially those in non-English languages or from lesser-known journals. Additionally, citation counts may favor well-established authors or publications with more time to accumulate citations, overlooking newer or less cited but equally valuable research. Environmental issues in developing regions may have been underrepresented by previous studies that focused on developed countries or regions with more research output. With all of these biases or gaps in bibliometric analysis, it might not fully show how important or relevant research is because it lacks qualitative data and background information. As a result, this study recommended that, rather than relying solely on Scopus, data from other databases, such as Web of Science, Google Scholar, and Microsoft Academic, be included to ensure broader coverage of publications. In the future, researchers may have a big effect on bibliometric studies of EPI research by adding publications that are not indexed to get a fuller picture of the research output.

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