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Carbon transparency in global supply chains: The mediating role of institutional and innovative capacity

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ABSTRACT

The aim of this bibliometric study is to examine carbon transparency within global supply chains and the mediating roles of institutional and innovative capacities. The study retrieved 116 documents from Scopus and Web of Science databases for the period 2001–2023. The study unveils three developmental phases. The early phase (2001–2010) lays the foundation for holistic sustainable manufacturing and sets the stage for subsequent exploration of topics like carbon transparency and eco-design. The second phase (2011–2015) shifts focus to the practical implementation of sustainable manufacturing and eco-conscious supply chains. The third phase (2016–2020) scrutinizes institutional pressures and innovations in measuring environmental impact of supply chains. The most recent phase (2021–2023) highlights a growing interest in innovation, particularly in developing countries, emphasizing technological contributions to sustainable development across economic and environmental dimensions. The key factors propelling the exponential growth of research in this domain, include heightened global awareness of climate change, a focus on sustainable development goals and transition to green economies, and the increasing complexity of contemporary supply chains. The study also highlighted developing countries' commitment to carbon transparency and sustainability, offering insights from Brazil and Malaysia.

1. Introduction

There is growing institutional pressure for firms to report their carbon emissions and environmental impact and promote transparency in their supply chains and a concerning trend has emerged. For instance, in 2020, 96 % of surveyed suppliers reported their carbon footprint, a figure that has declined to 89 % in 2022. This decline signals the presence of challenges in carbon reporting practices. Furthermore, according to a study conducted by [1], a global non-profit organization facilitating a disclosure system for companies and cities to report their environmental impact, only 75 % shared their targets for reduction. Noteworthy, of the 18,500+ companies disclosing through CDP in 2022, more than 7,000 companies reported engagement with their suppliers on climate change [2].

Another study by [3] found that large companies are more incentivized to adopt carbon management systems and make compensations due to reputational risks and social and economic pressure. The same study also reported that even if global buyers drive voluntary engagement in carbon management, their power becomes weaker at the subcontracting stage in supply chains in developing countries [3].

According to a report by CDP in 2022, more than half of suppliers (56 %) did not have any climate targets at all, and only 2.5 % of reporting suppliers have approved science-based targets [4]. However, the same report found that 75 % of suppliers reported their Scope 1 and 2 emissions and took action to reduce these emissions by a total of 231 million tons of CO2e [5]. In 2021, Target Corporation reported that 52 % of their top 80 % of suppliers, by spend, equating to 301 suppliers, set science-based scope 1 and 2 goals [6]. Equinix, another company, made progress towards its goal of engaging 66 % of its suppliers by qualified emissions settings to set a Science-Based Target (SBT), with 17 % of suppliers involved in FY22 [7]. Avary Holding, Canon, and Hon Hai also have initiatives to track the environmental performance of their suppliers and encourage the disclosure of carbon emissions [8].

Carbon transparency within global supply chains has evolved

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significantly over time, marked by key milestones, foundational studies, theoretical advances, and pivotal technological innovations. The establishment of the Partnership for Carbon Transparency (PACT) by Ref. [9] marked a significant milestone, focusing on the development of global infrastructure for product-level emission accounting and exchange. Additionally, the European Union's Green Deal and Climate Law, as outlined by Ref. [10], set binding targets for emissions reduction and climate neutrality by 2050. Moreover, Artificial Intelligence (AI) enabled circular economy policies [11], leverage machine learning for predicting and optimizing global energy and climate scenarios. Technological advancements have played a crucial role in advancing carbon transparency. Cloud computing [9], facilitates the transition of applications to the cloud, reducing carbon footprints. Blockchain technology [12], ensures secure and transparent recording and verification of carbon transactions. Furthermore, AI applications, as highlighted by Ref. [13,14], automate carbon accounting processes and data analysis, enhancing carbon management. The integration of technological advancements and policy shifts will shape future scenarios in carbon transparency. AI applications, as projected by [12], can significantly reduce global greenhouse gas emissions by 1.5 %–4.0 % by 2030. Big data analytics promise more accurate predictions and enhanced carbon footprint analysis [13,14], aiding in emission reduction efforts. Moreover, international agreements and government regulations, highlighted by [10], will continue to drive global efforts towards decarbonization and sustainability goals. In conclusion, the integration of AI, big data analytics, blockchain technology, and international agreements will likely play a pivotal role in shaping the future of carbon transparency. These innovative technologies hold the potential to drive innovation, enhance data accuracy, and accelerate the transition to a sustainable low-carbon economy, addressing the challenges of climate change and environmental sustainability on a global scale.

The mediating role of institutional and innovative capacity in promoting carbon transparency in global supply chains is an essential area of research, and strategies for fostering more carbon transparency in supply chains are needed [15]. Supply chains generate around 60 % of all carbon emissions globally, and addressing supply chain sustainability is vital in fighting against climate change [16,17]. However, there are still challenges in achieving transparency in global supply chains, including opaque carbon accounting and tracking practices and the lack of accurate product-level emissions data in the upstream supply chain [16]. Collaboration and partnering between multiple players in the value chain is necessary to address these challenges [16]. There are also tools and technologies available to promote transparency in global supply chains, such as carbon accounting solutions and the Value Chain Carbon Transparency Pathfinder for fast-moving consumer goods [16, 18].

The interplay between institutional and innovative capacities can influence the effectiveness of efforts to promote carbon transparency. Institutional pressures and managerial incentives can elicit carbon transparency [19,20], while institutional openness can significantly reduce carbon emissions through investment effects [21,22]. Organizations are under increasing pressure to decarbonize, but struggle to create transparency on emissions across their value chains [23,24].

The Partnership for Carbon Transparency (PACT) is resolving this challenge by developing the global methodological and technological infrastructure needed for product-level emission accounting and exchange [25]. Additionally, the Pathfinder Framework creates clear guidance for carbon accounting along value chains, supporting organizations in sharing their emissions data with customers and suppliers [26].

The Pathfinder Network facilitates the peer-to-peer exchange of such data by creating a standardized approach and ensuring interoperability between tech solutions [27]. The Pathfinder Ecosystem [28] brings together stakeholders from a range of industries, technology players, industry-focused initiatives, standard-setting organizations, reporting bodies, and regulators to leverage synergies and combine extensive expertise towards a common objective.

Carbon transparency in global supply chains is relatively new and increasing. This is due to several factors, including an increased awareness of the environmental impacts of global supply chains [29–31]. Growing pressure from NGOs, consumers, investors, and regulators for businesses to reduce their carbon emissions [32–34]. Technological advances that make it easier to measure and report carbon emissions [35,36]. This study aims to fill this gap by providing an extensive concept of supplier carbon transparency, a comprehensive analysis of its external/internal drivers, and investigating when institutional pressures are more/less effective in eliciting supplier carbon transparency.

The previous studies have provided a range of insights into carbon transparency in global supply chains. For instance, [37] found that carbon emissions across stages in a supply chain can constitute a significant threat that warrants careful attention in the design phase of supply chains. Das and Jharkharia [38] found that carbon governance is a strategic imperative for adopting low-carbon supply chain practices. Watari et al. [39] found that institutional instruments that enhance the resource governance of entire low-carbon technology supply chains and circular economy practices are important for promoting carbon transparency. Montecchi et al. [40] developed a framework for examining how supply chain transparency is enabled, which researchers can use to guide future studies and practitioners to identify, diagnose, and address modern challenges facing supply chains. Chen [41] found that manufacturers with greater inventory leanness and an economical process structure tend to attain lower firm-level and supply-chain carbon intensities. Zu et al. [42] reported that environmental regulations from the market, government, and operation can promote dynamic low-carbon production in the supply chain. A study by [43] found that multinational enterprises and their international supply chains can have large carbon footprints, but mitigation potential exists. Hofman et al. [44] argue that different institutional factors indicate divergent effects on supply chain collaboration and product/process eco-innovation. Brun et al. [45] found that NGOs significantly impact supply chain transparency. In addition, [46] found that consumers leverage increased supply chain transparency.

These studies provide a strong foundation for this research. Specifically, the study will build on these previous studies by providing a more comprehensive and systematic literature analysis, identifying emerging trends and research gaps, and investigating when institutional pressures are more/less effective in eliciting supplier carbon transparency.

Despite the increasing interest in carbon transparency within global supply chains, there remains a notable dearth of systematic or bibliometric research on the subject, particularly regarding the mediating influence of institutional and innovative capacities. This gap underscores the necessity for more extensive and systematic analyses of existing literature to discern key research streams, emerging trends, and areas of investigation. Hence, our study stands out for its comprehensive examination of the drivers behind supplier carbon transparency and its assessment of the effectiveness of institutional pressures in fostering transparency. By building upon previous research, we offer a more structured literature analysis that identifies emerging patterns and explores the role of institutional and innovative capacities. Given the limited bibliometric research in this area, there is an evident need for a more thorough examination of the existing literature to guide future research and address emerging challenges adequately. Consequently, our paper represents a timely and crucial effort to enhance understanding, identify gaps, and provide insights into promoting supplier carbon transparency to mitigate the environmental impacts of global supply chains.

The research objectives of our study are to comprehensively investigate the evolving landscape of carbon transparency within global supply chains, taking into account the challenges and trends observed over time. We aim to analyze the mediating role of institutional and innovative capacities in promoting carbon transparency across supply chain networks. Additionally, we seek to identify the underlying drivers behind supplier carbon transparency and evaluate the effectiveness of institutional pressures in fostering transparency initiatives. Through a rigorous literature analysis, our study aims to identify emerging patterns, research gaps, and areas requiring further investigation in the realm of carbon transparency. Ultimately, we endeavour to offer actionable insights into promoting supplier carbon transparency as a strategic approach to mitigate the environmental impacts of global supply chains. These objectives provide a structured framework for our research, guiding our analysis and contributing to the advancement of knowledge in the field of supply chain sustainability and carbon transparency.

This paper is timely and important for several reasons. First, it will help to advance the understanding of carbon transparency in global supply chains by providing a comprehensive and systematic analysis of the existing literature. Second, it will help identify emerging trends and research gaps, guiding future research efforts. Third, it will provide insights into how to promote supplier carbon transparency, which is essential for reducing global supply chains' environmental impacts.

2. Methodology

The primary purpose of this research paper is to conduct a bibliometric review of existing literature. The review intends to comprehensively analyze and understand the mediating role of institutional and innovative capacity in promoting carbon transparency within global supply chains. By synthesizing current knowledge and identifying key trends and insights in this field, the research aims to comprehensively understand the mechanisms that influence and facilitate carbon transparency, ultimately contributing to more sustainable and environmentally responsible supply chain practices. Furthermore, the study seeks to bridge the gap in our understanding of how institutional pressures, managerial incentives, and innovative capacity interplay in shaping the adoption of environmentally responsible strategies and to provide recommendations for enhancing sustainability and reducing carbon emissions within global supply chains.

2.1. Software and tools used in the bibliometric and scientometric evaluation

This study used an array of tools and software to undertake an extensive bibliometric and scientometric analysis within the context of carbon transparency in global supply chains and the mediating role of institutional and innovative capacity. When selecting software for this analysis, we deliberately chose Biblioshiny, a software solution highly regarded by previous researchers for its robust capabilities in generating comprehensive descriptive statistics and uncovering emerging publication trends, as Aria and Cuccurullo [47] noted. Additionally, we utilized VOSviewer, a well-recognized software in bibliometrics and scientometrics. It is renowned for its ability to visualize and dissect intricate networks of scholarly literature developed by van Eck and Waltman [48]. This choice reflects our commitment to employing state-of-the-art methodologies akin to a biologist utilizing cutting-edge laboratory equipment to delve into the intricate dynamics of a complex biological system.

2.2. Methodological framework for bibliometric and scientometric review

The bibliometric and scientometric reviews presented here followed a systematic approach. The research methodology was initiated by conducting a comprehensive bibliometric search, leveraging the Scopus and Web of Science (WoS) databases. Subsequently, data collected from these two sources were merged into a unified dataset. The data collection was conducted as of October 20, 2023, spanning publications from 2001 to 2023. The choice of Scopus was motivated by its extensive coverage of recent journals, surpassing the Web of Science in this aspect. While the Web of Science is renowned for its comprehensive scientific citation coverage, Scopus outperforms journal diversity and inclusivity, drawing from a wider range of sources for citation data.

This meticulous approach laid a solid foundation for our analysis of the field, which focuses on comparing bibliometric analysis using the Scopus and Web of Science databases to create a comprehensive global dataset that incorporates data from both sources [49,50].

2.2.1. Field 1: Carbon transparency

Field 1 (Table 1) captures the comprehensive scope of carbon transparency research in global supply chains. It encompasses various aspects, such as (i) measuring and reporting greenhouse gas (GHG) emissions. For example, a company in the garment industry might track its GHG emissions from its own operations, as well as from its suppliers' operations and the transportation of its products. (ii) Disclosing GHG emissions to stakeholders: For example, a publicly traded company might publish its GHG emissions in its annual report. (iii) Reducing GHG emissions: For example, a food company might invest in renewable energy to power its factories and reduce its reliance on fossil fuels. By including these keywords, Field 1 provides a holistic perspective on how organizations within the complex web of global supply chains manage, disclose, and reduce their carbon emissions.

2.2.2. Field 2: Global supply Chains

Field 2 (see Table 1) captures the comprehensive scope of research related to global supply chains. It encompasses various aspects, such as (i) the design and management of supply chains across international borders: For example, a company in the automotive industry might have a complex global supply chain that includes suppliers in multiple countries. (ii) the sustainability and resilience of supply chains: For example, a company in the food industry might be interested in researching how to reduce its supply chain's environmental impact or making its supply chain more resilient to disruptions. (iii) the social and ethical implications of global supply chains: For example, a company in the garment industry might be interested in researching on how to ensure fair labor practices in its supply chain. By including these keywords, Field 2 provides a holistic perspective on global supply chains and their impact on the environment, society, and the economy.

2.2.3. Field 3: The mediating role of institutional and innovative capacity

Field 3 (Table 1) captures the comprehensive scope of research related to institutional and innovative capacity. It encompasses various aspects, such as (i) The ability of organizations to learn and adapt to new technologies and practices related to carbon transparency. For example, a company in the energy sector might invest in research and development to develop new technologies for capturing and storing carbon dioxide emissions. (ii) The role of regulations and incentives in driving innovation in carbon transparency: For example, a government might implement a carbon tax to incentivize businesses to reduce their greenhouse gas emissions. (iii) The importance of corporate social responsibility and sustainability in promoting carbon transparency: For example, a company might adopt a sustainable procurement policy to ensure its suppliers meet certain environmental standards. Field 3 provides a holistic perspective on the factors influencing institutional and innovative capacity and their role in promoting carbon transparency by including these keywords.

Thus, the three fields, each with its distinct focus, converge to fulfil the study's overarching purpose: to shed light on the multifaceted relationship between carbon transparency, global supply chains, and the mediating forces that drive it. By interconnecting these fields, we aim to provide a holistic understanding of this intricate ecosystem and pave way for future research in this growing field. The study follows the flow chart described in Fig. 1.

Table 1
Search query used in SCOPUS and WoS databases to gather the data.

		Criteria
Logical Statement	Field 1	(TITLE-ABS-KEY ("carbon transparency") OR TITLE-ABS-KEY ("carbon accounting") OR TITLE-ABS-KEY ("carbon disclosure") OR TITLE-ABS-KEY ("carbon neutrality") OR TITLE-ABS-KEY ("carbon reduction") OR TITLE-ABS-KEY ("carbon tracking") OR TITLE-ABS-KEY ("climate change mitigation") OR TITLE-ABS-KEY ("decarbonization") OR TITLE-ABS-KEY ("emissions accounting") OR TITLE-ABS-KEY ("environmental sustainability") OR TITLE-ABS-KEY ("green procurement") OR TITLE-ABS-KEY ("low-carbon production") OR TITLE-ABS-KEY ("net zero supply chains") OR TITLE-ABS-KEY ("renewable energy") OR TITLE-ABS-KEY ("scope 3 emissions") OR TITLE-ABS-KEY ("supplier emissions") OR TITLE-ABS-KEY ("sustainability metrics") OR TITLE-ABS-KEY ("sustainable manufacturing") OR TITLE-ABS-KEY ("value chain carbon transparency")) AND
	Field 2	(TITLE-ABS-KEY ("global supply chains") OR TITLE-ABS-KEY ("global value chains") OR TITLE-ABS-KEY ("green supply chains") OR TITLE-ABS-KEY ("net zero supply chains") OR TITLE-ABS-KEY ("resource-efficient supply chain") OR TITLE-ABS-KEY ("responsible supply chains") OR TITLE-ABS-KEY ("supply chain sustainability") OR TITLE-ABS-KEY ("supply chain traceability") OR TITLE-ABS-KEY ("supply chain transparency") OR TITLE-ABS-KEY ("sustainable agricultural supply chains") OR TITLE-ABS-KEY ("sustainable distribution") OR TITLE-ABS-KEY ("sustainable inventory management") OR TITLE-ABS-KEY ("sustainable manufacturing") OR TITLE-ABS-KEY ("sustainable materials sourcing") OR TITLE-ABS-KEY ("sustainable packaging") OR TITLE-ABS-KEY ("sustainable procurement") OR TITLE-ABS-KEY ("sustainable product life cycles") OR TITLE-ABS-KEY ("sustainable transportation") OR TITLE-ABS-KEY ("value chain mapping")) AND
	Field 3	(TITLE-ABS-KEY ("absorptive capacity") OR TITLE-ABS-KEY ("climate disclosures") OR TITLE-ABS-KEY ("corporate social responsibility") OR TITLE-ABS-KEY ("eco-innovation capacity") OR TITLE-ABS-KEY ("environmental accountability") OR TITLE-ABS-KEY ("environmental disclosure") OR TITLE-ABS-KEY ("environmental governance") OR TITLE-ABS-KEY ("environmental management") OR TITLE-ABS-KEY ("environmental performance") OR TITLE-ABS-KEY ("environmental policy") OR TITLE-ABS-KEY ("environmental regulation") OR TITLE-ABS-KEY ("esg performance") OR TITLE-ABS-KEY ("innovative capacity") OR TITLE-ABS-KEY ("institutional factors") OR TITLE-ABS-KEY ("institutional pressures") OR TITLE-ABS-KEY ("normative pressure") OR TITLE-ABS-KEY ("r&d into materials substitutes") OR TITLE-ABS-KEY ("sustainability metrics") OR TITLE-ABS-KEY ("sustainable innovation") OR TITLE-ABS-KEY ("sustainable practices"))
Inclusion		1 . The document is published in the Scopus or Web of Science databases; 2 . The document is classified as an article; 3 . The document is in its final, published form; 4 . The document contains the keywords of interest; 5 . The document is related to the subject areas of business, economics, econometrics and finance or social sciences; 6 . The document is written in English.
Exclusion		1 . The document is not in English; 2 . The document type is not a journal article; 3 . The document is not related to business, economics, econometrics and finance or social sciences;
Human Review		1 . Manual review of the titles and abstracts for each paper.

Source: Author's Elaboration

2.3. Inclusion and exclusion criteria

The inclusion and exclusion criteria provided in Table 1 are designed to identify a set of journal articles relevant to the research topic on the mediating role of institutional and innovative capacity in promoting carbon transparency within the complex network of global supply chains. The inclusion criteria ensures that the articles are (i)Published in high-quality databases, including Scopus and WoS. (ii) Classified as articles. (iii) In their final, published form. (iv) Related to the subject areas of interest. (v) Written in English. That is, the exclusion criteria ensures that the articles are not in other languages. Other document types (e.g., book chapters, conference proceedings). Related to other subject areas. The selection also includes a manual review of the titles and abstracts of the articles to ensure that each document is related to the study's purpose. By applying these criteria, the selection can ensure confidently that the identified articles are relevant to the research and can help to achieve the study purpose.

2.4. Assessment of bias and rigor

The study recognizes the importance of rigor and bias assessment in ensuring the reliability of the selected articles. This involves a rigorous evaluation of the methodology employed in individual studies. The inclusion criteria, such as publication in reputable databases and adherence to subject relevance, inherently contribute to the overall quality and reliability of the selected articles. Additionally, the manual review process further acts as a layer of scrutiny to assess potential biases in the titles and abstracts of the articles. This dual-layered approach, encompassing both clear inclusion and exclusion criteria and a meticulous manual review, enhances the robustness of the article selection process, thereby fortifying the study's foundation and ensuring the credibility of the research outcomes.

3. Results and findings

3.1. Main information of each data

Table 2 shows that the combined dataset is the largest and most comprehensive compared to the individual databases (after removing duplicates), with the widest range of sources, documents, and references. It also has the highest average number of citations per document, suggesting that it includes the most highly cited and influential research on the topic.

The percentage of documents with international co-authors is highest in the Web of Science database, followed by the Scopus database and the combined dataset. This suggests that the Scopus database may be a more comprehensive source of information on carbon transparency, global supply chains, and the mediating role of institutional and innovative capacity. However, the Web of Science database may be a better source of information on research that is being conducted by international collaborations. Overall, the data in the table suggests that the combined dataset is the best source of information for this study.

3.2. Annual science production

Fig. 2 shows the evolution of annual scientific production on the topic of carbon transparency, global supply chains, and the mediating role of institutional and innovative capacity, from 2001 to 2023.

The data shows a significant increase in publications on this topic over the past two decades. This increase can be explained by a number of factors, including:

The heightened recognition of climate change and the imperative to curtail greenhouse gas emissions. Additionally, there is a mounting emphasis on sustainability and corporate ethical obligations. Adding the escalating intricacy of worldwide supply chain networks necessitating enhanced transparency. And the emergence of novel technologies and

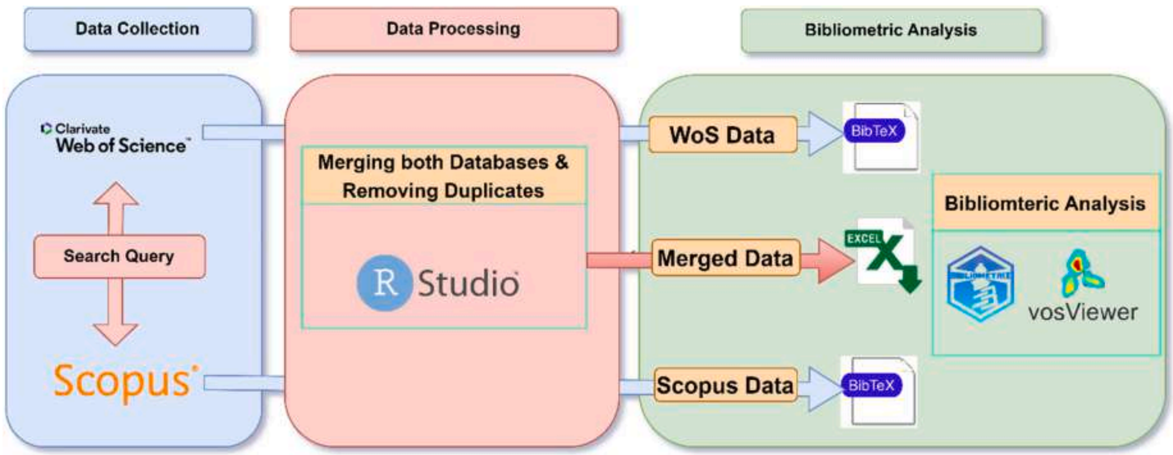

Fig. 1. Flow Chart of the research strategy adopted in this study.
Source: Author's Elaboration

Table 2
General information regarding each database.

Description	Scopus	WoS	Combined
MAIN INFORMATION ABOUT DATA			
Timespan	2001; 2023	2013; 2023	2001; 2023
Sources (Journals, Books, etc)	104	32	116
Documents	247	50	270
Annual Growth Rate %	15.76	28.21	17.23
Document Average Age	4.74	3.08	4.54
Average citations per doc	57.73	39.94	55.32
References	16388	4128	18623
DOCUMENT CONTENTS			
Keywords Plus (ID)	1251	249	1370
Author's Keywords (DE)	841	238	920
AUTHORS			
Authors	738	143	766
Authors of single-authored docs	22	6	24
AUTHORS COLLABORATION			
Single-authored docs	22	6	24
Co-Authors per Doc	3.38	2.94	3.32
International co-authorships %	33.2	40	2.963
DOCUMENT TYPES			
article	247	45	265

Source: Author's Elaboration using biblioshiny developed by Aria and Cuccurullo [47].

methodologies for gauging and documenting carbon emissions. However, other specific events that may have contributed to the increase in scientific production on this topic include:

- The Kyoto Protocol (1997) set binding targets for developed countries to reduce their greenhouse gas emissions.
- The Paris Agreement (2015) set a global goal of limiting global warming to well below 2 °C above pre-industrial levels.
- The Sustainable Development Goals (2015) include a goal to "promote sustainable consumption and production patterns."
- The rise of corporate social responsibility and environmental, social, and governance (ESG) investing.
- The development of new technologies for measuring and reporting carbon emissions, such as blockchain and artificial intelligence.

It is also worth noting that the data in the table shows that the number of publications from Web of Science (WoS) has been consistently lower than from Scopus. This may be because WoS has a more selective indexing policy than Scopus. However, it is also possible that it reflects that Scopus is a more comprehensive database for research on this topic, as it includes a wider range of sources, including conference proceedings and books.

3.3. Most relevant sources

Table 3 shows the most relevant sources for research on carbon

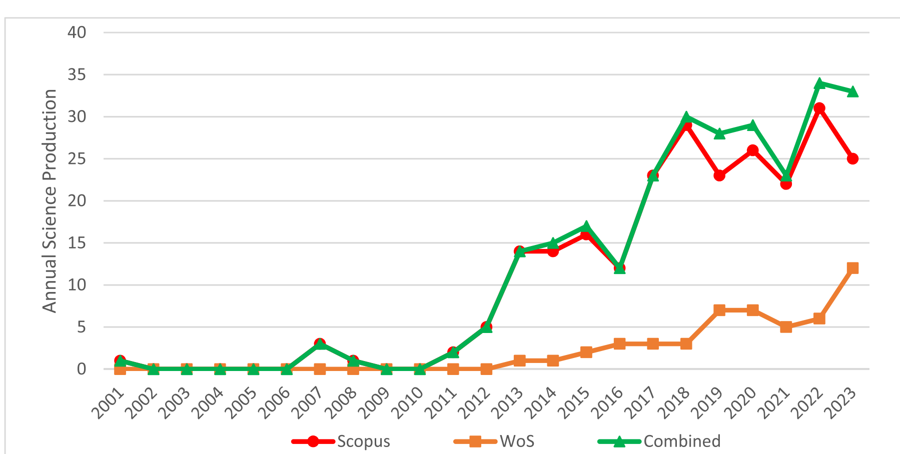

Fig. 2. The evolution of annual scientific production.
Source: Author's Elaboration

Table 3
Most relevant sources.

Scopus		WoS		Combined	
Sources	N	Sources 2	N2	Sources	N
JOURNAL OF CLEANER PRODUCTION	46	BUSINESS STRATEGY AND THE ENVIRONMENT	5	JOURNAL OF CLEANER PRODUCTION	46
SUSTAINABILITY (SWITZERLAND)	21	BENCHMARKING-AN INTERNATIONAL JOURNAL	3	SUSTAINABILITY (SWITZERLAND)	21
RESOURCES, CONSERVATION AND RECYCLING	17	ECONOMIC RESEARCH-EKONOMSKA ISTRAZIVANJA	3	RESOURCES, CONSERVATION AND RECYCLING	17
INTERNATIONAL JOURNAL OF PRODUCTION ECONOMICS	10	INTERNATIONAL JOURNAL OF OPERATIONS \& PRODUCTION MANAGEMENT	3	BUSINESS STRATEGY AND THE ENVIRONMENT	10
INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH	8	JOURNAL OF MANUFACTURING TECHNOLOGY MANAGEMENT	3	INTERNATIONAL JOURNAL OF PRODUCTION ECONOMICS	10
BUSINESS STRATEGY AND THE ENVIRONMENT	7	INTERNATIONAL JOURNAL OF LOGISTICS-RESEARCH AND APPLICATIONS	2	INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH	8
BENCHMARKING	5	INTERNATIONAL JOURNAL OF PRODUCTIVITY AND PERFORMANCE MANAGEMENT	2	JOURNAL OF MANUFACTURING TECHNOLOGY MANAGEMENT	7
ECONOMIC RESEARCH-EKONOMSKA ISTRAZIVANJA	4	JOURNAL OF PURCHASING AND SUPPLY MANAGEMENT	2	BENCHMARKING	5
INTERNATIONAL JOURNAL OF LOGISTICS RESEARCH AND APPLICATIONS	4	REVIEW OF INTERNATIONAL POLITICAL ECONOMY	2	ECONOMIC RESEARCH-EKONOMSKA ISTRAZIVANJA	4
JOURNAL OF MANUFACTURING TECHNOLOGY MANAGEMENT	4	SUPPLY CHAIN MANAGEMENT-AN INTERNATIONAL JOURNAL	2	INTERNATIONAL JOURNAL OF LOGISTICS RESEARCH AND APPLICATIONS	4
SUPPLY CHAIN MANAGEMENT	4	TECHNOLOGICAL FORECASTING AND SOCIAL CHANGE	2	SUPPLY CHAIN MANAGEMENT	4
INTERNATIONAL JOURNAL OF OPERATIONS AND PRODUCTION MANAGEMENT	3	BUSINESS ETHICS QUARTERLY	1	INTERNATIONAL JOURNAL OF OPERATIONS AND PRODUCTION MANAGEMENT	3
INTERNATIONAL JOURNAL OF PRECISION ENGINEERING AND MANUFACTURING - GREEN TECHNOLOGY	3	CONSTRUCTION ECONOMICS AND BUILDING	1	INTERNATIONAL JOURNAL OF PRECISION ENGINEERING AND MANUFACTURING - GREEN TECHNOLOGY	3
INTERNATIONAL JOURNAL OF PRODUCTIVITY AND QUALITY MANAGEMENT	3	CORPORATE SOCIAL RESPONSIBILITY AND ENVIRONMENTAL MANAGEMENT	1	INTERNATIONAL JOURNAL OF PRODUCTIVITY AND QUALITY MANAGEMENT	3
INTERNATIONAL JOURNAL OF SUSTAINABLE MANUFACTURING	3	ECONOMIC CHANGE AND RESTRUCTURING	1	INTERNATIONAL JOURNAL OF SUSTAINABLE MANUFACTURING	3
CLEANER LOGISTICS AND SUPPLY CHAIN	2	ENGINEERING MANAGEMENT JOURNAL	1	CLEANER LOGISTICS AND SUPPLY CHAIN	2
ENVIRONMENT, DEVELOPMENT AND SUSTAINABILITY	2	EUROPEAN JOURNAL OF OPERATIONAL RESEARCH	1	ENVIRONMENT, DEVELOPMENT AND SUSTAINABILITY	2
GLOBAL ENVIRONMENTAL CHANGE	2	GLOBAL BUSINESS REVIEW	1	GLOBAL ENVIRONMENTAL CHANGE	2
INTERNATIONAL JOURNAL OF PROCESS MANAGEMENT AND BENCHMARKING	2	GLOBALIZATIONS	1	INTERNATIONAL JOURNAL OF PROCESS MANAGEMENT AND BENCHMARKING	2
INTERNATIONAL JOURNAL OF SERVICES AND OPERATIONS MANAGEMENT	2	INDEPENDENT JOURNAL OF MANAGEMENT \& PRODUCTION	1	INTERNATIONAL JOURNAL OF PRODUCTIVITY AND PERFORMANCE MANAGEMENT	2

Source: Author's Elaboration

transparency, global supply chains, and the mediating role of institutional and innovative capacity based on the number of publications from each source cited by other publications in the field.

The top three sources in Scopus and WoS are the Journal of Cleaner Production, Sustainability (Switzerland), and Resources, Conservation and Recycling. These journals are all leaders in publishing research on sustainability and environmental management. Other notable sources on this topic include Business Strategy and the Environment. International Journal of Production Economics. International Journal of Production Research. Benchmarking: An International Journal. Economic Research-Ekonomska Istraživanja. International Journal of Logistics Research and Applications. Journal of Manufacturing Technology Management. Supply Chain Management: An International Journal.

These journals publish research on a wide range of topics related to carbon transparency, global supply chains, and the mediating role of institutional and innovative capacity, including Carbon accounting and reporting. Sustainable supply chain management. Green manufacturing and logistics. The role of government and industry in promoting carbon transparency. The impact of new technologies on carbon emissions The fact that these journals are among the most relevant sources for research on this topic suggests that it is a growing and important field of study.

The table also shows some overlap between the most relevant sources in Scopus and WoS. However, there are also some unique sources in each database. This suggests that it is important to consult both databases when researching this topic.

3.4. *Most relevant authors*

Table 4 shows the most relevant authors in the field of research based on the number of publications they have authored that other publications in the field have cited. The top three authors in Scopus and WoS are Giancarlo Ingarao, Joseph Sarkis, and Faraaz Badurdeen.

These authors have made significant contributions to the field by researching various topics, including Carbon accounting and reporting. Sustainable supply chain management. Green manufacturing and logistics. The role of government and industry in promoting carbon transparency. The impact of new technologies on carbon emissions. The fact that these authors are among the most relevant authors in this field suggests that they are leading experts on this topic. Thus, their research has helped to shape our understanding of the challenges and opportunities associated with reducing greenhouse gas emissions from global supply chains.

3.5. *Country scientific production*

Table 5 shows the most relevant countries in terms of scientific production. The top three countries are the United States, China, and India. These countries are all leaders in terms of both the quantity and quality of research on this topic.

Some facts can explain these results, such as The United States (US) has been a leader in climate change research and policy for many years.

Table 4
Most relevant authors in this field of research.

Scopus		WoS		Combined	
Authors	Articles	Authors	Articles	Authors	Articles
INGARAO G	5	CARTER CR	2	INGARAO G	5
SARKIS J	5	DAUVERGNE P	2	SARKIS J	5
BADURDEEN F	4	ROGERS ZS	2	BADURDEEN F	4
EVANS S	4	SARKIS J	2	BALL P	4
GARZA-REYES JA	4	ABBAS Q	1	EVANS S	4
GREEN KW	4	ABDUL-RASHID SH	1	GARZA-REYES J	4
BAUMGARTNER RJ	3	ADIL GK	1	GREEN K	4
DI LORENZO R	3	AGRAWAL D	1	HUANG C	4
GENOVESE A	3	AGRAWAL R	1	KUMAR A	4
HUANG CH	3	AJMAL MM	1	LEE J	4

Source: Author's Elaboration.

Table 5
Most relevant country's scientific production.

Scopus		WoS		Combined	
region	Freq	region	Freq	region	Freq
USA	93	INDIA	34	USA	49
CHINA	77	USA	28	INDIA	48
INDIA	66	CHINA	20	UK	37
UK	58	UK	20	CHINA	29
ITALY	35	MALAYSIA	19	ITALY	19
MALAYSIA	31	CANADA	7	MALAYSIA	19
BRAZIL	18	ITALY	7	BRAZIL	10
PAKISTAN	17	DENMARK	6	DENMARK	8
AUSTRALIA	14	AUSTRALIA	5	PAKISTAN	8
GERMANY	14	GREECE	4	SPAIN	8
SPAIN	10	SOUTH AFRICA	4	AUSTRALIA	6
SWEDEN	10	FINLAND	3	FINLAND	5
SOUTH KOREA	9	NETHERLANDS	3	GERMANY	5
DENMARK	8	NORWAY	3	NORWAY	5
AUSTRIA	7	PAKISTAN	3	PHILIPPINES	5
CANADA	7	PHILIPPINES	3	TURKEY	5
FINLAND	7	SPAIN	3	AUSTRIA	4
BELGIUM	6	TURKEY	3	CANADA	4
FRANCE	6	BRAZIL	2	JAPAN	4
GREECE	6	FRANCE	2	SOUTH AFRICA	4

Source: Author's Elaboration.

Additionally, the US is also home to several leading universities and research institutions researching carbon transparency, global supply chains, and the mediating role of institutional and innovative capacity.

China is the world's largest emitter of greenhouse gases. China also invests heavily in renewable energy and other technologies to reduce its emissions. This investment leads to a growing body of research on carbon transparency, global supply chains, and the mediating role of institutional and innovative capacity.

India is another major emitter of greenhouse gases. India is also a rapidly developing country, and its economy is becoming increasingly integrated into the global supply chain. This leads to a growing interest in research on carbon transparency, global supply chains, and the mediating role of institutional and innovative capacity.

Other notable countries in this field include the United Kingdom, Italy, Malaysia, Brazil, Pakistan, Australia, Germany, Spain, Sweden, South Korea, and Denmark. These countries are all leaders in either their research output or economic importance in the global supply chain.

It is also worth noting that the table shows a significant amount of research on this topic being conducted in developing countries. This is a positive development, as it suggests that these countries are committed to addressing the challenges of climate change.

3.6. Trend topics evolution

Four distinctive periods were identified based on the trend topics evolution from 2001 to 2023 (see Fig. 3):

3.6.1. Phase 1 (2001–2010): Environmental planning, industrial ecology, eco-design

The initial phase of sustainable manufacturing research (2001–2010) was driven by the growing awareness of the environmental impact of manufacturing activities, the increasing demand for sustainable products and services, and the development of new technologies and processes that could help manufacturers reduce their environmental impact. During this phase, researchers focused on developing a holistic approach to sustainable manufacturing, encompassing environmental planning, industrial ecology, and eco-design. Environmental planning focuses on developing and implementing policies and programs to protect the environment. Industrial ecology studies the flow of materials and energy between industrial systems and the natural environment. Eco-design is designing products and services to minimize their environmental impact throughout their life cycle, from raw material extraction to disposal.

3.6.2. Phase 2 (2011–2015): Sustainable manufacturing, sustainable development, environmental management

The second phase of sustainable manufacturing research (2011–2015) was focused on implementing sustainable manufacturing practices and developing sustainable supply chains. This was driven by the growing recognition of the importance of sustainable manufacturing for both the environment and the economy, the increasing focus on climate change and the need to reduce greenhouse gas emissions.

During this phase, researchers and manufacturers focused on developing and implementing specific practices to reduce the environmental impact of manufacturing operations and supply chains. This included reducing the use of resources, energy, and emissions, designing products and services for recyclability and reuse, and developing sustainable sourcing practices.

3.6.3. Phase 3 (2016–2020): Supply chain management, carbon footprint, carbon emission

The third phase of sustainable manufacturing research (2016–2020) was focused on measuring and reducing the environmental impact of manufacturing supply chains. This was driven by the growing awareness of the importance of reducing greenhouse gas emissions from the manufacturing sector and the increasing demand for sustainable products and services from consumers and businesses.

During this phase, researchers and manufacturers focused on developing and implementing new tools and methods to measure and reduce the environmental impact of manufacturing supply chains. This included developing life cycle assessment (LCA) tools and carbon footprint calculators. Researchers also began to develop new strategies for supply chain collaboration to reduce the environmental impact of manufacturing.

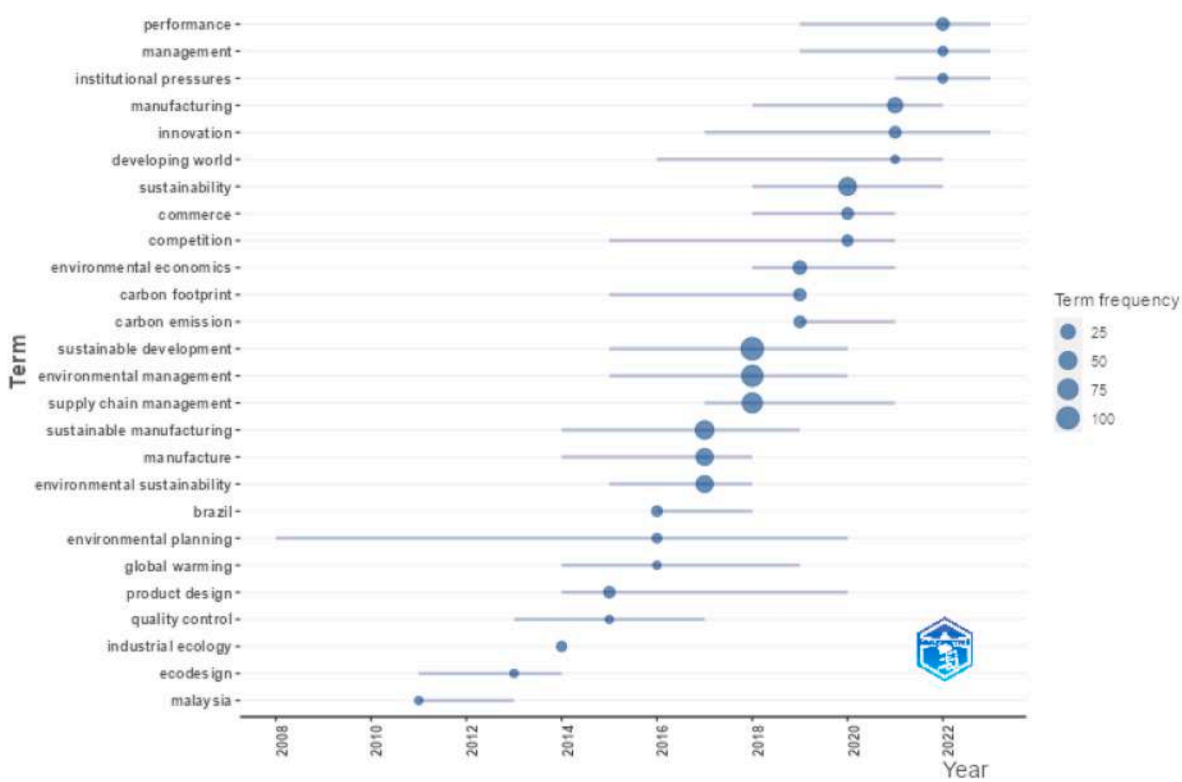

Fig. 3. Trend topics evolution.
Source: Author's Elaboration using biblioshiny developed by Aria and Cuccurullo [47].

3.6.4. *Phase 4 (2021–2023): Innovation, developing world, performance, institutional pressures*

Developing new sustainable manufacturing technologies and practices and implementing them in developing countries (such as Brazil and Malaysia, as illustrated in Fig. 3). The fourth phase of sustainable manufacturing research (2021–2023) is focused on developing new sustainable manufacturing technologies and practices and implementing them in developing countries. It also includes measuring and improving the performance of sustainable manufacturing practices and responding to institutional pressures to adopt sustainable practices. During this phase, researchers and manufacturers are focused on developing and implementing new sustainable manufacturing technologies and practices, such as Renewable energy, Energy efficiency, Circular economy principles, Advanced materials, Digital manufacturing.

They are also focused on developing sustainable manufacturing solutions for the developing world, where there is a growing demand for sustainable products and services but also significant challenges regarding access to resources and technologies.

The presence of the keywords "Brazil" and "Malaysia" in the table reflects the growing importance of this topic in the developing world. Brazil and Malaysia have both made significant commitments to sustainable development.

3.7. *Co-occurrence word network*

Fig. 4 shows a group of co-occurrence word networks consisting of three clusters (cluster 1 in red color, cluster 2 in blue color, cluster 3 in green color), each with distinct keywords that represent specific themes. Each cluster consists of:

Cluster 1 (Environmental Sustainability and Carbon Transparency):

Cluster 1 captures keywords from Fields 1 (Carbon Transparency) and Field 2 (Global Supply Chains). This cluster primarily focuses on environmental sustainability and carbon transparency in global supply chains. It includes keywords such as "environmental sustainability,"

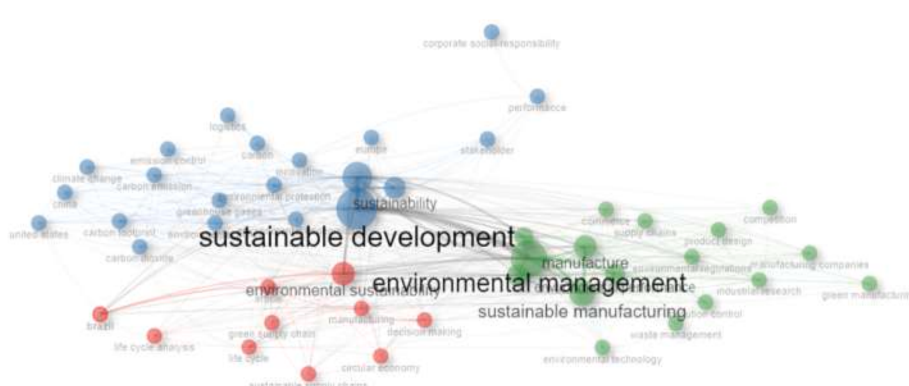

Fig. 4. Co-occurrence word network.
Source: Author's Elaboration using VOSviewer developed by van Eck and Waltman [48].

"manufacturing," "decision making," "life cycle analysis," "sustainable supply chains," and more. These keywords indicate research topics related to measuring, disclosing, and reducing carbon emissions within the context of sustainable supply chains and environmental practices. While, keywords like "green supply chain" and "circular economy" highlight the importance of adopting eco-friendly and sustainable practices in supply chains.

Cluster 2 (Sustainability and Supply Chain Management):

Cluster 2 aligns with Field 2 (Global Supply Chains) in the study and encompasses supply chain management's economic and sustainability dimensions. This cluster revolves around sustainability, supply chain management, and environmental topics. It includes keywords such as "sustainability," "environmental economics," "environmental policy," "performance," "carbon footprint," "climate change," "carbon dioxide," "carbon emission," "innovation," and more. These keywords are related to various aspects of supply chain management, focusing on sustainability and environmental factors, including performance metrics, carbon emissions, and innovation.

Cluster 3 (Environmental Impact and Manufacturing):

Cluster 3 corresponds to Field 3 (The Mediating Role of Institutional and Innovative Capacity) in the study, highlighting the role of manufacturing and environmental impact in the context of institutional and innovative capacity. Cluster 3 is centred around environmental impact and manufacturing. It includes keywords such as "environmental sustainability," "sustainable manufacturing," "environmental impact," "manufacture," "environmental performance," "green supply chain management," and more. These keywords are associated with research areas concerning the environmental implications of manufacturing processes, sustainability practices, and supply chain management. Topics like "waste management" and "green manufacturing" emphasize the importance of environmentally conscious manufacturing practices.

The co-occurrence word network also reveals some interesting insights into the evolution of sustainable manufacturing research. For example, the keywords "environmental sustainability", "life cycle", and "eco-design" appear prominently in the first cluster, which suggests that these topics were central to the early stages of sustainable manufacturing research. In contrast, the keywords "circular economy", "performance", and "carbon footprint" appear more prominently in the second and third clusters, which suggests that these topics have become more important in recent years.

The co-occurrence word network also shows that sustainable manufacturing research is increasingly focused on developing and implementing practical solutions. For example, the keywords "supply chain management", "green supply chain management", and "environmental management" appear prominently in all three clusters. This suggests that researchers and practitioners are increasingly focused on finding ways to integrate sustainable practices into existing business operations.

4. Discussion

There has been a significant increase in publications on carbon transparency, global supply chains, and institutional and innovative capacity. One driver of the growing academic discourse in this field is the increasing institutionalization of carbon transparency. Corporations are now not only obligated to measure and disclose their carbon emissions but are also compelled to ensure transparency in these reporting processes, as underscored by [51]. Transparency emerges as a potent tool to demystify the complexities that characterize global supply chains. Gardner et al. [52] emphasize that transparency is vital in empowering the various stakeholders involved in these intricate networks. It is increasingly evident that the quality of relationships within supply chains significantly influences transparency. According to [45], strong supply chain relationships directly impact enhancing transparency.

Several key factors have contributed to the exponential growth of research in this field. These include the heightened global awareness of climate change, as evidenced by the findings of [53]. Additionally, the laser focus on sustainability, as documented by Ref. [3], further fuels the research endeavour. The increasing complexity of contemporary supply chains, as elucidated by sources such as SGSC [54] and the World Economic Forum [55], adds to the urgency and necessity of research. Lastly, the development of advanced emission measurement technologies, as highlighted by the Green Investment Group [53], equips researchers with powerful tools to investigate and address environmental challenges more comprehensively.

Various seminal events have acted as catalysts for the intensification of research in this domain such as the Kyoto Protocol, signed in 1997. Furthermore, the Paris Agreement inked in 2015 and the Sustainable Development Goals (SDGs) adopted by the United Nations in 2015. Concurrently, the rise of corporate social responsibility, as observed by Rycke [56], has contributed to a heightened scholarly focus in this area. Lastly, the development and adoption of state-of-the-art emission measurement technologies as detailed by [55], have been pivotal in driving research endeavours forward.

4.1. *Developing countries' commitment to carbon transparency and sustainability: Insights from Brazil and Malaysia*

United States, China, and India are at the forefront of research in this research domain. These countries are prominent in both the quantity and quality of research output, reflecting their leadership in addressing climate change and reducing emissions.

Beyond these leading nations, Brazil, one of the world's largest countries, significantly influences global carbon emissions. The country has committed to reducing its greenhouse gas emissions and has implemented policies to promote sustainable development [57,58]. Nevertheless, challenges persist, particularly concerning the establishment of a regulated carbon market and the recent surge in deforestation emissions, which jeopardizes Brazil's national determined contribution (NDC) targets to the World Bank (2023).

Malaysia, a major palm oil producer, faces environmental challenges linked to deforestation and greenhouse gas emissions. However, the nation has showcased a strong commitment to addressing these issues. Specifically, Malaysia has implemented policies aimed at reducing carbon emissions and advancing sustainable development. Notably, introducing a carbon pricing mechanism incentivises companies to lower their carbon emissions, all while curbing deforestation and ensuring long-term economic growth [59]. Malaysia's endeavours can serve as an exemplary model for other developing countries aiming to transition towards decarbonized economies [60]).

Brazil has a National Policy on Sustainable Manufacturing, and Malaysia has a National Green Technology Policy. These policies have helped to promote sustainable manufacturing research and practice in these countries. Brazil and Malaysia are also home to several leading sustainable manufacturing companies. For example, the Brazilian company Natura is a global leader in the production of sustainable cosmetics and personal care products. The Malaysian company Sime Darby is a leading producer of sustainable palm oil.

4.2. *Paradigm shifts in sustainable manufacturing: A two-decade evolution towards carbon transparency in global supply chains*

Fig. 3 represents the phases of the chronological development, illustrating how the field's focus has shifted over the past two decades. In particular, the transition from one phase to the next reflects not only the evolving priorities within this field of research but also the broader contextual changes in environmental consciousness and industry needs.

4.2.1 The early phase (2001–2010): characterized by a foundational focus on holistic sustainable manufacturing, laid the groundwork for the subsequent exploration of topics such as carbon transparency and eco-design. The phase aligns with the study's aim to uncover the role of institutions and innovation in enhancing sustainability practices. As environmental awareness grew and the demand for sustainability increased, it became apparent that a shift towards more eco-conscious supply chains and sustainable manufacturing practices was necessary, as found in Ref. [61,62]) and for the BRICS zone in Aldakhil et al. [63].

4.2.2 The second phase (2011–2015): the spotlight shifted toward implementing sustainable manufacturing and developing eco-conscious supply chains practically. This shift was driven by the recognition of sustainability's dual benefits for the environment and the economy, along with a heightened focus on climate change mitigation as reported by [64–66].

4.2.3 The third phase (2016–2020): aligns closely with the study's objective of understanding institutional pressures and innovations in measuring and reducing the environmental impact of global supply chains. Notably, during this period, the proliferation of tools and technologies designed to measure emissions played a pivotal role in driving this shift.

It's worth noting that the study's findings indicate limited support for the factors hypothesized to influence carbon footprint reduction and economic benefits. Indeed, most firms that embarked on carbon reduction initiatives were yet to realize the full effectiveness of these efforts [67,68] estimate that, with reasonable levels of adoption, green consumer actions could reduce the EU's CO2 footprint significantly. Lastly, it's crucial to consider that carbon emissions reduction should encompass both direct and indirect influences throughout entire supply chains [42,69,70].

4.2.4 The most recent phase (2021–2023): underscores the growing interest in innovation and its relationship with developing countries. It is revealed that technological innovation makes a simultaneous contribution to all three dimensions of sustainable development but primarily in the case of affluent countries [71]. However, its impact extends to middle-income countries' economic and environmental dimensions; with no discernible effect in low-income countries [71]. Technological innovation is found to be significantly and positively related to industrial sustainable development, signifying its mediating role in the relationship between flexible environmental policy and industrial sustainability (Yuan et al., 2020). In addition, the study underscores the pivotal role of deep-tech in propelling sustainability and profitability in different sectors. Industrial are encouraged to actively seek collaborations with various partners, including emerging deep-tech firms. These collaborations provide access to novel technologies and specialized expertise, enabling the application of deep tech in both products and processes, fostering sustainability and profitability [72].

4.3. Empowering carbon transparency: Key policy measures and technological innovations shaping environmental accountability

The interplay between technological advances and policy frameworks plays a crucial role in promoting carbon transparency. Specific successful policy measures have been developed by institutions and governments for promoting carbon transparency:

Partnership for Carbon Transparency (PACT): This initiative focuses on developing the global methodological and technological infrastructure required for product-level emission accounting and exchange. The PACT program [25] consists of three components: The Pathfinder Framework [26], Pathfinder Network [27], and Pathfinder Ecosystem [28]. Together, these components aim to empower organizations to tackle and reduce emissions at scale.

Carbon Pricing: Implementing robust carbon pricing mechanisms, such as a global average of at least $85 per ton by 2030, can drive investments in green technologies and cleaner sources [73].

Transparency Requirements: Strengthening climate-related disclosure requirements and standardizing taxonomies can help investors make low-carbon investment decisions [73].

European Union Green Deal and Climate Law: The EU Green Deal sets binding targets to cut emissions by 55 % by 2030 compared to 1990 levels and to reach climate neutrality by 2050 [74]. The Climate Law ensures that the EU meets its commitments under the Paris Agreement and the UN Sustainable Development Goals.

Australian Government's Clean Energy Regulator: Investments in clean hydrogen, carbon capture and storage, and payments to farmers through the national soil carbon innovation challenge contribute to Australia's efforts to reduce emissions.

Argentinian Congress Passed Climate Change Law: Argentina established minimum standards for climate change, including the implementation of a National Climate Change Response Plan, a National System for GHG Inventory, and monitoring of mitigation initiatives.

Swedish Pigouvian Tax Mechanisms: Sweden introduced Pigouvian tax mechanisms to help achieve carbon neutrality goals. Pigovian taxes internalize externalities associated with carbon emissions, making polluters pay for the damage caused by their actions.

Global Carbon Pricing Initiatives: By 2021, 64 carbon pricing initiatives were implemented globally, covering 45 national jurisdictions and 21.5 % of global emissions. Carbon pricing mechanisms, such as cap-and-trade systems and carbon taxes, play a significant role in reducing emissions and driving innovation. These examples highlight the importance of collaborative efforts, strategic planning, and targeted regulation in promoting carbon transparency and driving decarbonization efforts.

These are some examples of successful technological innovations for promoting carbon transparency:

- **Pathfinder Framework**: Provides clear guidance for carbon accounting along value chains, facilitating the sharing of emissions data among organizations WBCSD (2023b).
- **Pathfinder Network:** Facilitates peer-to-peer exchange of emissions data by creating a standardized approach, enhancing transparency and decarbonization efforts WBCSD. (2023c).
- **Data Exchange Technologies:** Updated technical specifications enable the exchange of product-related carbon emissions data using standardized technical language, accelerating carbon transparency and supply chain decarbonization at scale [75].
- **Cloud computing:** Moving applications to the cloud reduces the carbon footprint of organizations relative to maintaining onsite servers [76,77]. For instance, the carbon-aware control (CAC) framework effectively reduces electricity cost and carbon emission in geo-distributed cloud services by optimizing geographical load balancing, capacity right-sizing, and server speed scaling [78].
- **Blockchain technology:** offers secure, decentralized, and tamper-proof ways to record and verify carbon transactions, thereby improving transparency and traceability [79,80]. For example, the Improved Invasive Weed Mayfly Optimization (IIWMO) algorithm significantly improves the performance of a blockchain-based carbon footprint reduction system compared to existing approaches [81].
- **Artificial Intelligence (AI)-powered Solutions:** can automate complex carbon accounting processes, streamline data collection, and generate detailed reports, helping organizations to optimize their carbon management strategies. For example, Automated Machine Learning (AutoML) effectively manages AI complexities in energy management systems, aiding in microgrid energy optimization and net zero carbon emissions [82].
- **Internet of Things (IoT) Devices:** IoT sensors and connected equipment allow organizations to gather real-time data on energy usage, waste generation, and other emissions sources, enabling proactive carbon management (Paruchuri et al., 2018), see also EcoLogic, an IoT platform, can effectively control carbon emissions in vehicles through real-time monitoring, smart notifications, and vehicle power limitations [83].

While these innovations show promise, it is essential to note that success depends on context, regional differences, and local regulatory environments. Continuous evaluation and refinement of these tools and techniques will ensure their ongoing efficacy in promoting carbon transparency and decarbonization efforts around the globe.

5. Conclusion

In this bibliometric study, we have endeavoured to address significant gaps in the field of carbon transparency within global supply chains, focusing on understanding the role of institutional pressures, and supplier transparency. The findings offer valuable insights into these complex dynamics and contribute to the broader discourse on sustainability, innovation, and transparency in supply chain management.

Exploring supplier carbon transparency has allowed us to establish a robust conceptual framework that considers a myriad of external and internal drivers. By delving into the intricate interplay of these factors, we have gained a deeper understanding of when institutional pressures are effective in eliciting supplier carbon transparency. This knowledge is crucial in addressing the environmental challenges posed by global supply chains.

Despite the growing interest in the subject, this research gap highlights the need for more systematic and in-depth analyses of the existing body of literature, ultimately pinpointing key research streams and areas needing further exploration.

The contributions of this study are multifaceted in the current context. First and foremost, we have advanced the understanding of carbon transparency in global supply chains by conducting a comprehensive and bibliometric analysis of the existing literature. Our research also serves as a guide, identifying emerging trends and research gaps that will be instrumental for future research efforts. Most importantly, our study offers valuable insights into promoting supplier carbon transparency, a critical factor in reducing the environmental impacts of global supply chains.

In conclusion, this study identifies several promising directions for future research to advance our comprehension and understanding of the mediating role of institutional and innovative capacity in promoting carbon transparency within global supply chains. To facilitate a more structured and academically oriented presentation, the key research avenues are delineated in this paragraph.

Future investigations should first focus on exploring emerging data sources and advanced techniques that have the potential to augment data supremacy in academic research. This entails a comprehensive exploration of cutting-edge methodologies, encompassing artificial intelligence, machine learning, and the robust analytics of big data. It is crucial to ascertain how these evolving technologies can be harnessed to enhance the credibility and rigor of academic research.

A comprehensive analysis of the effectiveness of institutional pressures and regulatory frameworks in cultivating carbon transparency within global supply chains is of paramount importance. This scrutiny becomes even more significant in the context of emerging markets, where the dynamics and challenges may differ significantly from established economies. In addition, it is imperative to delve into the pivotal role of non-governmental organizations (NGOs) and their influence in fortifying supply chain transparency and environmental governance. Investigating their contributions to the promotion of sustainable practices is essential.

Expanding the scope to examine developing countries' commitment to carbon transparency and sustainability presents an invaluable research avenue. Moreover, evaluating the impacts of carbon pricing mechanisms, such as carbon taxes and cap-and-trade systems, is essential in incentivizing corporations to curtail their carbon emissions.

Drawing from the insights gleaned through the study a proposed framework for evaluating digital technologies in carbon transparency offers a foundational structure for future research endeavours. By delineating key aspects such as scope and visibility, data quality and accuracy, decision-making, emission reduction strategies, and real-world context integration, the framework provides a systematic approach to assessing the efficacy of digital tools across supply chains. This framework serves as a preliminary model that can be expanded and refined through future investigations. By delving deeper into each metric and evaluation method, researchers can uncover nuanced insights into the impact of digital technologies on carbon transparency. Additionally, exploring the scalability, integration, and cost-effectiveness criteria, alongside conducting pilot studies, and fostering collaboration with industry stakeholders, will contribute to the ongoing refinement and applicability of the framework in diverse contexts.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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