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The Green Finance Blind Spot: A Bibliometric Analysis on GVC, Green Finance and Decarbonization

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Abstract

As the Middle East and North Africa (MENA) region seeks to harness private enterprise for economic transformation, the decarbonization of Global Value Chains (GVCs) has emerged as a critical challenge for competitiveness. While the technological imperatives are clear, the financial architecture required to support the region's SMEs in this transition remains undefined. This study assesses the state of the evidence base through a two-stage bibliometric and qualitative analysis. A global search of Scopus and Web of Science (N=297) reveals a "green finance blind spot," where research prioritizes carbon accounting over financial mechanisms. A targeted regional search (N=12) confirms this gap is a near-total "research blackout" regarding the MENA context. By triangulating these findings with regional policy ("grey") literature, this paper diagnoses the specific risks of this knowledge vacuum and proposes a concrete research and policy agenda to bridge the gap between measurement and financial mobilization.

Keywords: Global Value Chains (GVCs), Green Finance, Decarbonization, MENA Region, Bibliometric Analysis

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1. Introduction

As the Middle East and North Africa (MENA) region seeks to harness private enterprise for its economic transformation, the decarbonization of Global Value Chains (GVCs) has emerged as a critical structural challenge. For the region's private sector, particularly the Micro, Small, and Medium Enterprises (MSMEs) that form the backbone of industrial supply chains, adapting to new global standards is no longer just an environmental aspiration but a prerequisite for market survival. The rise of mandatory carbon pricing mechanisms, most notably the EU's Carbon Border Adjustment Mechanism (CBAM), threatens to erode the comparative advantage of MENA exporters in key sectors such as textiles, automotive, and fertilizers. To maintain market access and drive a private-sector-led transition, regional firms must urgently decarbonize their production processes.

However, this industrial transformation requires capital. While the technological pathways for decarbonization are increasingly clear, the financial architecture to support them is not. A fundamental barrier to this market-enabling transition is the lack of accessible, scalable financial instruments designed specifically for supply chain decarbonization. To design effective policies that crowd in private investment and de-risk this transition, policymakers require a solid evidence base. This study asks: does such an evidence base exist?

To answer this question, we conducted a comprehensive two-stage bibliometric and qualitative analysis. First, a global search of the Scopus and Web of Science databases yielded 297 peer-reviewed documents at the intersection of GVCs, green finance, and decarbonization. Second, a parallel, methodologically identical search targeting the MENA region yielded a strikingly small result: only 12 unique articles.

This study systematically diagnoses the policy implications of this research landscape, offering a threefold contribution. First, our bibliometric analysis identifies a global 'green finance blind spot': while the literature has mastered the diagnostic measurement of supply chain emissions—focusing heavily on carbon accounting and logistics, it systematically overlooks the financial mechanisms required to mitigate them. Second, we empirically document an 'academic blackout' specific to the MENA region, highlighting the disconnect between the region's urgent exposure to trade risks and the absence of peer-reviewed guidance on funding the transition. Third, to address these deficits, the paper proposes a targeted research agenda and policy framework designed to bridge the gap between diagnostic metrics and financial mobilization.

This paper uses this data-driven diagnosis as a foundation to propose a concrete, evidence-informed research agenda. It is structured as follows: Section 2 outlines the SPAR-4-SLR methodology. Section 3 presents the results of the global bibliometric analysis and the regional sub-sample analysis. Section 4 bridges the academic gap by analysing the regional policy landscape through a review of grey literature. Finally, Section 5 proposes a targeted research agenda to bridge the gap between diagnostic measurement and financial mobilization, securing the region's position in a decarbonizing global economy.

2. Methodology

This study employs a two-stage bibliometric and qualitative analysis to systematically map the research landscape of Global Value Chains (GVCs), green finance, and decarbonization, with a specific focus on identifying knowledge gaps in the MENA region. To ensure transparency and replicability, we followed the SPAR-4-SLR protocol (Assembling, Arranging, Assessing, and Advancing) as outlined in Table 1 (Paul et al., 2021)

Bibliometric data was retrieved from both Scopus and Web of Science (WoS) databases up to February 2025. We implemented a comparative two-stage search strategy. First, we conducted a Global Search using a query combining keywords for GVCs, green finance, and decarbonization. Second, to assess the specific evidence base for the Middle East and North Africa, we ran a targeted Regional Search by adding a fourth Boolean string containing comprehensive geographic keywords (e.g., Turkey, Egypt, MENA, Arab). While the global search yielded a robust

dataset, the targeted regional search yielded a strikingly small sub-sample of only 12 unique documents, necessitating a qualitative approach for that subset.

For both queries, we restricted results to publications categorized under "Economics, Econometrics and Finance" (Scopus) and "Economics" (WoS). This ensured the analysis focused specifically on economic research, excluding publications from engineering or environmental sciences that lack a financial/market perspective. Furthermore, we limited document types to articles and review articles to ensure peer-reviewed quality. Following the method outlined by Lim et al. (2024), the datasets from Scopus and WoS were merged and harmonized using the Bibliometrix R package (Biblioshiny). This process automatically removed duplicates and standardized metadata, resulting in a final global corpus of 297 documents.

Table 2 provides a summary of the global dataset. Our data spans from 1995 to 2025 and includes 297 documents sourced from 110 sources. The annual growth rate is 15.78% (calculated for the complete years 1995-2024 to accurately reflect the evolutionary trend), which indicates a highly expanding field, and reflects a growing interest in the subject area. This is also seen in the average document age of 4.7 years, and the average citation per document of 24.49. this is a highly dynamic research field, highly impactful and relevant.

For the global dataset, the analysis integrates two primary bibliometric approaches: Performance Analysis and Science Mapping (Donthu et al., 2021; Passas, 2024). Performance analysis, conducted using the Bibliometrix R

Table 2 Overview of the final dataset

Databases	Scopus and WOS
Timespan	1995:2025
Sources	110
Documents	297
Annual growth rate %	9,9[1] (15.78%)
Document average age	4,7
Average citations per doc	24,49
References	16820
DOCUMENT CONTENTS	
Keywords plus	1566
Author's keywords	1165
AUTHORS	
Authors	822
Authors of single-authored docs	39
AUTHORS COLLABORATION	
Single-authored docs	40
Co-authors per doc	3,29
International co-authorships %	18,52
DOCUMENT TYPES	
Article	277
Article; book chapter	1
Article; early access	9
Article; proceedings paper	3
Review	7

Source: compiled by the authors

Table 1 SPAR-4-SLR review protocol

phase	Consideration	Details
Assembling	Search focus	GVC, green finance and decarbonization
	Search (keyword) string	Look at Table 11 Appendi
	Search period	Up to February 2025
	Search database	Scopus and Web of Science
	Search field	title, abstract, keywords
	Search results	2721 from Scopus 2359 from WOS
Arranging	Document type	Articles and review articles
	Language	No filter
	Publication stage	No filter
	Subject (research) areas	Economics, Econometrics and Finance in Scopus Economics in WOS
	Filtered results	225 from Scopus 173 from WOS
	Consolidated results (after merging)	297 documents after combining and cleaning Scopus and Web of Science datasets
Assessing	Analysis method	Bibliometric analysis - Performance analysis - Science mapping
	Agenda proposal method	Evolution of the field Conceptual and intellectual structure Gap spotting

Source: compiled by the authors

[1] The annual growth rate by excluding 2025 (capped at 2024) is 15.78%

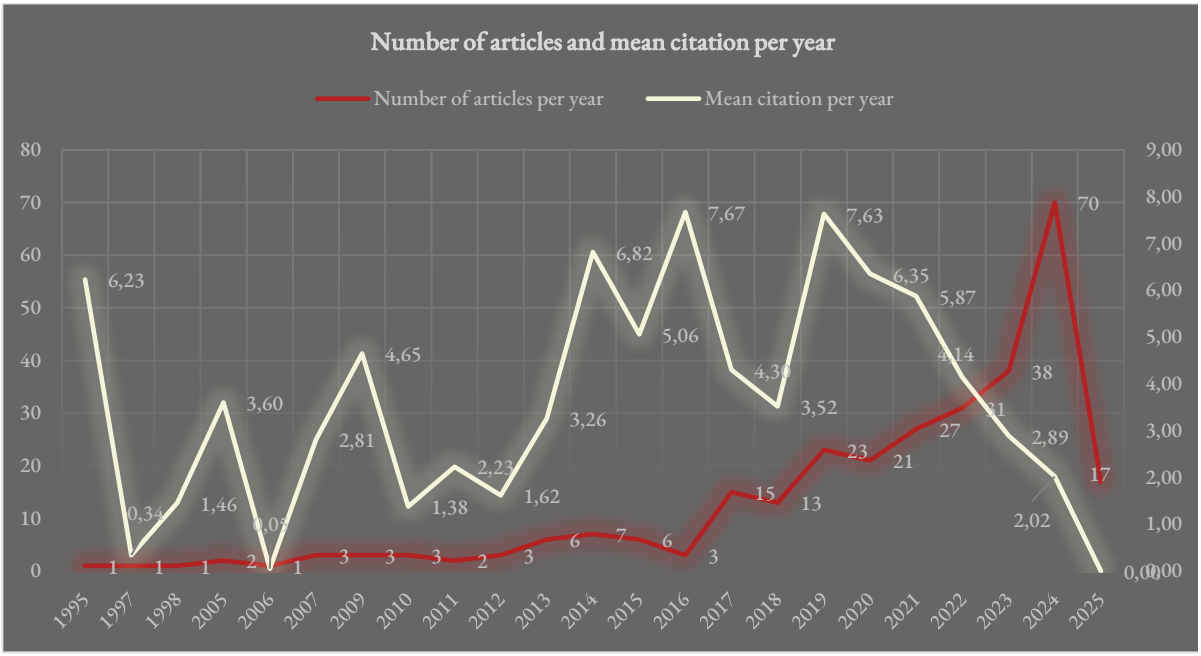
package (Aria & Cuccurullo, 2017) evaluated research productivity, and identify key contributors. Science mapping techniques were utilized to explore the field's intellectual and conceptual structure. Specifically, co-citation analysis to reveal the foundational knowledge base and influential historical works, while keyword co-occurrence analysis to map the current thematic structure, conceptual relationships, and temporal evolution of topics. To enhance the accuracy of the KCA we uses a thesaurus file (Figure 6) in Appendices to group synonyms and standardize keyword terminology. These mapping analyses and associated visualizations were primarily conducted using VOSviewer software (Van Eck & Waltman, 2010), including the application of a thesaurus file (Figure 7, Appendices) for keyword standardization. For the regional sub-sample (N=12), given that it was insufficient for statistical bibliometric analysis, we conducted a qualitative content analysis. Each paper was reviewed to determine its thematic focus and relevance to the core intersection of finance and GVC decarbonization. This step was crucial to empirically verify the "research blackout" in the region. Crucially, the interpretation of all quantitative results and visualizations was guided by the sensemaking framework (Lim & Kumar, 2024)

3. Performance analysis

3.1. Productivity and impact evaluated through publication and citation trends

Figure 1 shows the number of articles produced each year, and the average citation for documents for that year. The low numbers in 2025 are to be expected. The number of articles increased in this field significantly throughout the years, with a significant increase in 2017 and in 2023. To reach its highest in 2024 with 70 articles published. This suggests that this research field is gaining wider interest and an expanding of research activity. Mean Citations per Year normalize the number of citations by the number of years since it was published. Earlier years despite not having a high number of articles produced, show higher citation impact, indicating foundational knowledge and a sustained interest in these articles which were probably foundational in exploring the intersection of GVCs, green Finance, and decarbonization, introducing key concepts and laying the theoretical and empirical foundations for this field of research. However, as we will see, this surge in volume has not necessarily translated into geographic diversity, raising questions about the applicability of these global trends to developing regions like MENA.

Figure 1: Number of articles and mean citations per year.



Source: generated by the author using data retrieved from Scopus and Web of Science (WoS)

Using the graph, we can categorize the development of this field in three stages. The first from 1995 to 2013 which produced the foundational articles in this field, especially with high mean citation despite the lower number of articles. The second period spans from 2014 until 2019 witnessed relative growth and diversification reflecting growing interest. This may be explained by the adoption of the Paris agreement (2015) and Sustainable Development Goals (SDGs), a wider institutional framework and support across countries and international institutions, the adoption of Carbon Pricing and Regulations such as missions Trading Scheme (ETS) and Carbon Border Adjustment Mechanisms (CBAMs), raised awareness and evidence about climate change and its urgency, increased importance of GVC, the wider adoption of Environmental, Social, and Governance (ESG) concepts; and finally more accessible quantitative tools with better and more widely available data. These articles maintain relatively high mean citations per year.

The third period spans from 2020 until today, characterized by an explosion of research activity. This explosion is likely the continuation of the increased interest from the previous period but may also be driven by an increased urgency of addressing climate change and achieving net-zero targets (part of the SDGs) with more countries and corporations committing to net-zero emissions by mid-century; The growing importance of green finance globally and the integration of decarbonization strategies into GVCs, especially in light of geopolitical shifts and supply chain disruptions (e.g. COVID-19, energy crises).

It is thus of interest to look into some of the earlier articles with a high number of citations, as well as try to identify the research themes from each period.

3.2. Readings from highly cited research

This section reviews the most impactful articles in the field of interest. First, it examines the most cited papers for each of the periods identified before. It also reviews the most cited documents overall and those with the highest citations per year within the dataset, along with the most frequently locally cited references.

3.2.1. Reviews

3.2.1.1. The First Period: 1995-2013

Research in the first period (1995–2013) was primarily diagnostic, focusing on establishing the theoretical costs of carbon taxation and developing the initial methodologies for carbon accounting. The most cited research from this

Table 3 High-Impact Research on GVCs, Green Finance, and Decarbonization Across Three Periods (1995–2023)

First Period: 1995-2013			Second Period:2014-2019			Third Period: 2020 Onward		
Paper	TC[2]	TC per Year	Paper	TC	TC per Year	Paper	TC	TC per Year
Goulder L, 1995, Jenvironeconmanage	193	6,23	Soysal M, 2014, Int J Prod Econ	205	17,08	Gao Y, 2020, Energy Econ	252	42,00
Huang Y, 2009, Econ Syst Res	148	8,71	Chen X, 2019, Int J Prod Econ	173	24,71	Doliente S, 2020, Front Energy Res	166	27,67
Busch T, 2007, Ecol Econ	122	6,42	Fahimnia B, 2015, Int J Prod Econ	147	13,36	Ma S, 2021, Transp Res Pt E-Logist Transp Rev	114	22,80
Xu L, 2013, Resour Conserv Recycl	120	9,23	Nurjanni K, 2017, Int J Prod Econ	132	14,67	Liu A, 2021, Transp Res Pt E-Logist Transp Rev	81	16,20
Foran B, 2005, Ecol Econ	116	5,52	Beretta C, 2019, Resour Conserv Recycl	125	17,86	Khan S, 2021, Resource Policy	78	15,60

Source: Compiled by the author from Scopus and Web of Science datasets

period is by (Goulder, 1995) with 193 total citations (TC) and an average TC per year of 6.23 which reflects sustained relevance to the field. The main contributions of this paper are fourfold. First, it looked into tax interactions, examining how carbon taxes interact with pre-existing tax distortions (income taxes, for example) and showed how

[2] Total Citations

the latter amplifies the cost of introducing a carbon tax. This was a novel contribution as earlier studies often assumed a first-best economy (with no pre-existing taxes). Second, the study examined the potential of revenue recycling and found that while it lowers the cost of carbon taxes, it doesn't eliminate it. Thus, this finding challenged the 'double dividend' hypothesis[3]. Third, the authors tested the sensitivity of carbon taxes to Pre-Existing Tax Rates and found that welfare costs of carbon taxes are highly sensitive to their level. Fourth, the paper utilized a dynamic general equilibrium model, which allows for a detailed analysis of energy-sector dynamics and a comprehensive assessment of carbon tax impacts compared to previous models. In this regard, the paper laid the foundation for researching the interaction between environmental taxes and pre-existing taxes. It can be regarded as seminal work in the field of environmental economics as it shaped subsequent research on carbon pricing, revenue recycling, and the double dividend hypothesis.

(Huang et al., 2009) is the second most cited paper in this period with an average of 8.71 TC per year the article demonstrated how input-output analysis can be used as a screening tool for identifying sources of Scope-3 emissions[4], thus a better measurement for corporate carbon footprint, as it highlights the limitation of only relying on Scope-1 and Scope-2 emissions[5]. The paper also looked into the effectiveness of materiality thresholds in capturing the full carbon footprint and suggesting that for achieving high capture rates, IOA is highly recommended (especially for particularly complex sectors such as pharmaceuticals and electronics). The paper advocates for a hybrid approach that combines IOA with process-based life cycle assessment (LCA). IOA is used for screening for significant emissions sources, while LCA is used to provide detailed data for high-impact areas.

(Busch & Hoffmann, 2007) is the third most cited paper in the first period with 122 TC and an average TC per year of 6.42. this article argued for the integration of carbon-related risks into corporate risk management frameworks to assess the financial risks of global sustainability challenges. Focusing on both input (fossil fuel scarcity)[6], and output (climate change)[7], while encompassing the sourcing of critical materials within a company's value chain. The authors proposed a framework for the integration of carbon risk by recognizing the relevance of carbon constraints. They found that financial risks were asymmetrically distributed between and within sectors. An individual company's risk depended on their usage intensity and dependency on carbon-based materials and energy. Finally, financial markets were only recently beginning to incorporate these aspects into their evaluations.

The fourth most cited article (L. Xu et al., 2013) investigated the pressures that are driving the adoption of green supply chain management in India, and identified 32 pressures categorized in 5 groups[8]. They analysed their impacts across various sectors finding heterogenous impacts as large-scale and export-oriented industries faced stronger pressures compared to smaller or less export-focused sectors. The authors noted that multi-national firms identifying developed nations such as India and China as potential markets put these nations under pressure to adopt green concepts in supply chain operations.

(Foran et al., 2005) is the fifth most cited paper in the first period with a TC per year of 5.52. the authors proposed a robust framework that integrates sustainable supply chain management (SCM) with triple bottom line (TBL) accounting using input-output analysis (IOA). They developed a methodology to quantify the economic, social, and

[3] Double dividend is where environmental taxes both improve the environment and reduce overall tax distortions. (Goulder, 1995) showed that the second dividend is unlikely for carbon taxes.

[4] Indirect emissions from supply chains

[5] Direct and energy-related emissions

[6] Input constraints are related to the scarcity of fossil fuels and its consequences on corporate risk through price volatility and supply disruptions, which will probably increase due to resource depletion. These risks are more relevant for sectors heavily reliant on fossil.

[7] This includes both direct effects and indirect effects. The first related to damages for infrastructure, and resource availability. The second relates to regulatory changes, and shifts in consumer preferences. The energy, insurance, and agriculture sectors are particularly exposed to these risks

[8] Government policies and regulations; Marketability of the product and competitiveness; External factors in the supply chain; Financial factors and Production and operational factors

environmental impacts of production chains across 135 sectors of the Australian economy. This approach captured both direct and indirect effects of production chains providing a more comprehensive assessment of sustainability impacts across sectors, firms, and products. The authors applied this methodology to various sectors to demonstrate its relevance for both producers and consumers.

3.2.1.2. The Second Period: 2014-2019

The second period (2014–2019) marks a shift from theory to operational optimization, driven by the practical demands of supply chain management under emerging regulations. The most cited paper in the second period is by (Soysal et al., 2014) with 205 TC. The article uses a multi-objective linear programming model in order to optimize food logistics focusing on beef supply chains by integration economic costs and environmental impacts particularly carbon emissions. These can be influenced by multiple factors considered by the model such as transportation emissions, return hauls, product perishability. They applied their model to the international beef supply chain between Brazil and the EU. The model provided a Pareto frontier which illustrates the trade-offs between minimizing logistics costs and reducing Carbon Dioxide (CO_2) emissions.

The second most cited paper (Chen et al., 2019) with 173 citations aimed to look into the dynamics of green R&D cooperation within a two-echelon supply chain by examining how technological spillover, supply chain power structures and green research and development investments impact firms' decision to cooperate on green innovations by utilizing game-theoretical models to analyse these factors under different power structures. It also looks into the positive role of supply chain coordination through two-part tariff contracts in order to achieve pareto improvements, which is effective across all power structures. Green R&D cooperation between supply chain partners to improve economic performance, environmental outcomes, and social welfare. They emphasized the role of technological spillover effects which positively affected both economic and environmental performance. Leaders in the supply chain power structure are particularly important as they should have higher contribution levels to sustain cooperation.

(Fahimnia et al., 2015) introduced a comprehensive tactical supply chain planning model, a bi-objective Mixed-Integer Nonlinear Programming (MINLP) model which integrates both economic and environmental objectives, under a carbon tax policy, aiming to minimize both supply chain costs and carbon emissions. The model was solved

Table 4 Most 10 Cited Documents by the Number of Total Citations

Author(S) And Year	Title	Journal	TC	TC /Year
(Gao et al., 2020)	Evaluation of Effectiveness of China's Carbon Emissions Trading Scheme in Carbon Mitigation	Energy Economics	252	42,00
(Soysal et al., 2014)	Modelling Food Logistics Networks with Emission Considerations: The Case of an International Beef Supply Chain	International Journal of Production Economics	205	17,08
(Goulder, 1995)	Effects of Carbon Taxes in an Economy with Prior Tax Distortions: An Intertemporal General Equilibrium Analysis	Journal of Environmental Economics and Management	193	6,23
(Chen et al., 2019)	Firms' Green R&D Cooperation Behaviour in a Supply Chain: Technological Spillover, Power and Coordination	International Journal of Production Economics	173	24,71
(Doliente et al., 2020)	Bio-Aviation Fuel: A Comprehensive Review and Analysis of the Supply Chain Components	Frontiers in Energy Research	166	27,67
(Huang et al., 2009)	The Role of Input–Output Analysis for the Screening of Corporate Carbon Footprint's	Economic Systems Research	148	8,71
(Fahimnia et al., 2015)	Tactical Supply Chain Planning Under a Carbon Tax Policy Scheme: A Case Study	International Journal of Production Economics	147	13,36
(Nurjanni et al., 2017)	Green Supply Chain Design: A Mathematical Modelling Approach Based on a Multi-Objective Optimization Model	International Journal of Production Economics	132	14,67
(Beretta & Hellweg, 2019)	Potential Environmental Benefits from Food Waste Prevention in the Food Service Sector	Resources, Conservation and Recycling	125	17,86
(Busch & Hoffmann, 2007)	Emerging Carbon Constraints for Corporate Risk Management	Ecological Economics	122	6,42

Source: Compiled by the Author from Scopus and Web of Science Datasets

with a modified Cross-Entropy method and applied to the real-life case of Australian outdoor furniture manufacturers. The study provided empirical evidence of how carbon taxes impact supply chain costs and emissions, offering insights into the trade-offs between cost efficiency and environmental performance

(Nurjanni et al., 2017) presented a multi-objective mathematical optimization model for designing green supply chains (GSC), incorporating both economic and environmental objectives. The model aimed to reduce total costs and total carbon dioxide emissions; allowing for the evaluation of trade-offs; inn a closed-loop supply chain network with forward and reverse logistics, employing three different scalarization methods. The authors also employed sensitivity analysis to show the importance of cost structures and transportation modes in impacting the optimal supply chain design.

(Beretta & Hellweg, 2019) investigated the environmental benefits of food waste prevention in the food service sector, potentially contributing to the UN SDG 12.3. they analysed 13 case studies across various subsectors in order to quantify the status quo of food waste and the reduction potential of food waste and then using LCA to evaluate the environmental impacts associated with food waste finding that food waste contributed significantly to the environmental footprint of the food value chain with heterogenous effects[9]. They examined two scenarios of food waste reduction, a base scenario with a 38% reduction leading to a 41% reduction in climate impacts and a 30% reduction in biodiversity impacts. The second is an extended scenario leading to a 70% reduction by incorporating on-marketable vegetables and other measures. Finally, the authors presented six detailed case studies which showcasing the effectiveness of various measures. The authors emphasized the importance of targeting small individual caterers and implementing tailored measures.

3.2.1.3. The Third Period: 2020-onward

From 2020 onward, the literature pivoted toward impact evaluation and complex systems modeling, attempting to measure the effectiveness of specific policy interventions like ETS and green technology subsidies. (Gao et al., 2020) used a difference-in-differences (DID) and difference-in-difference-in-differences (DDD) to analyse data from 28 industries across 30 Chinese provinces from 2005 to 2015, aiming to evaluate the effectiveness of China's Carbon Emissions Trading Scheme (ETS) in reducing carbon emissions and focusing on both production-based and consumption-based emissions. They found that the ETS reduced emissions in pilot regions and industries significantly, with a particular stronger effect on production-based emissions. However, ETS also led to carbon leakage, which they identified as a significant issue, as emissions were outsourced from pilot to non-pilot regions. The authors suggested better emissions accounting and establishing national ETS. This finding is particularly salient for MENA economies currently grappling with the design of their own carbon pricing mechanisms to mitigate CBAM risks.

(Doliente et al., 2020) provided a comprehensive and detailed review of the bio-aviation fuel (BAF) supply chain by examining the economic and environmental performance of different feedstocks, production pathways, storage, and transport. They evaluated first-generation (1-G), second-generation (2-G), third-generation (3-G), and fourth-generation (4-G) feedstocks, as well as production pathways like Hydro-processed Esters and Fatty Acids (HEFA), Fischer-Tropsch (FT), and Alcohol-to-Jet (ATJ). They emphasize the trade-offs between economic viability, environmental impact, and scalability of different feedstocks options. Regarding Production Pathways, HEFA was identified as the most immediate solution. The article provides a whole-system supply chain perspective on BAF. The article shows the potential of BAF to reduce GHG emissions in the aviation sector by conducting a life cycle assessment.

(Ma et al., 2021) aimed to understand the interplay among technology investments, government intervention, and consumer preferences for green products in the context of sustainable supply chain management. The supply chain model the authors built consists of a manufacturer and a retailer. The manufacturer invests in green emission

[9] meat and fish are the most impactful in terms of climate change, while coffee and cocoa have high biodiversity impacts.

reduction technology (GERT) while the retailer invests in information disclosure technology (IDT) to communicate the green quality of products to consumers. The authors then examined different scenarios and used differential game theory to derive the optimal investment strategies and assess the impact of governmental policies on emission reduction and supply chain performance. They found that higher subsidies increase emission reduction and supply chain profit by incentivizing manufactures to invest more in GERT. Furthermore, they found that cost-sharing between the manufacturer and the retailer by subsidizing IDT, decreases emission reductions and supply chain performance, leading to pareto improvements. However, high Emission Standards Can Hurt Manufacturers by reducing his profits and doesn't decrease emissions, while the retailers remain unharmed. Thus, dynamic collaboration between manufacturers and retailers, supported by government intervention, is crucial for achieving sustainable supply chains. The authors also show the important role consumer preference has in driving GERT and IDT investments.

(A. Liu et al., 2021) proposed an integrated location-inventory-routing model that optimizes economic costs, carbon emissions and product freshness in order to address the challenges of managing perishable product supply chains in emerging markets. The authors used the YALMIP toolbox for solving the multi-objective optimization. The authors found trade-offs dynamics between the three objectives, and looked into the optimal Vehicle Speed which significantly affects economic costs and carbon emissions and found the optimal speed to be 90 km/h for manufacturer-to-distribution centre and 100 km/h for distribution centre-to-retailer.

(Khan et al., 2021) looked into the impacts Green Supply Chain Management (GSCM) practices on economic growth, environmental sustainability, and social performance in the EU, employing econometric techniques, including Generalized Method of Moments (GMM) and Fully Generalized Least Squares (FGLS). They introduced a composite GSCM index combining variables such as renewable energy consumption, environmental management, industry value-added, and regulatory pressure. They found that GSCM practices significantly reduce carbon emissions, fossil fuel consumption, water pollution-related deaths, pollution-related mortality rates, while also promoting economic growth through increased Foreign Direct Investment (FDI) inflows and trade openness. The also found a bidirectional causality between Gross Domestic Product (GDP) per capita and GSCM practices.

3.2.1.4. Most locally cited references

Looking into the most locally cited references. That means articles that are not necessarily in our dataset, but are widely referenced by the articles in the dataset. The most cited reference in our dataset is (B. Meng et al., 2018) with 20 citations. This article is aimed at integrating two lines of research: 1. trade in value-added; and 2. embodied emissions in trade into a unified framework that traces both economic and environmental impacts along GVCs. The paper uses a multi-regional input-output (MRIO) model based on the World Input-Output Database (WIOD) to trace CO_2 emissions and value-added while utilizing forward and backward industrial linkage-based decomposition techniques to separate emissions generated from domestic and international production processes which allows for a detailed understanding of how emissions are generated, transferred across borders, by country, sector and bilateral trade routes. They found that international trade has high environmental cost, as one unit of GDP generated through international trade generates more impact than domestic production. This is driven by high-carbon-intensity intermediate goods trade. Further, they showed that emission transfers do not occur only between developed and developing countries, but that they are increasingly occurring between developing countries, particularly China. The authors also showed that a country's position in GVCs significantly influence its emissions, as countries with higher participation have more foreign emission embodied in their exports. Looking into the differences between Consumption and Production-Based Emissions, the authors found that developed countries tend to have higher consumption base emissions which indicates that they are net importers of emissions. While the opposite is true for developing countries. Lastly, they found that upstream production energy structure impacts significantly the carbon intensity of exports.

Based on their study, they recommend addressing carbon leakage in GVCs through border carbon adjustments, they highlight the need for a shared responsibility framework between producers and consumers in different countries, and recommend moving beyond production-based emission accounting and incorporate consumption-based accounting. They also emphasize the need for promoting green energy in upstream production and strengthening environmental regulations in developing countries.

The second most cited reference locally is the one by (Koopman et al., 2014) in which they proposed an accounting model that decomposes a country's gross exports into value-added components and double-counted terms. Their model integrates vertical specialization and value-added trade measures thus linking official trade statistics with value-added measures which enhances the consistency of economic analysis. Further, the authors constructed an Inter-Country Input-Output (ICIO) Table which improves on previous databases. They used their framework to recompute revealed comparative advantages. They found that up to 25% of global exports contains double-counted intermediate goods. Advanced economies have higher domestic value-added returning domestically compared to emerging economies which have higher foreign content in exports. Further, revealed comparative advantages changes significantly using value-added instead of gross exports. They also found that trade costs get magnified through multi-stage production, which disproportionately affects countries with lower domestic value-added.

(Peters et al., 2011) investigates the role of international trade in the global emissions of CO2. They provide a detailed quantification of emissions transfers via international trade from 1990 until 2008. This paper also introduced and developed the concept of consumption-based emissions which contrasts with previous territorial; or production-based; emissions. The authors developed trade-linked global database for CO2 emissions covering 113 countries and 57 sectors for that period. This study employed three main methods: (1) Emissions Embodied in Bilateral Trade (EEBT) which focus on the domestic supply chain and bilateral trade; (2) a Multi-Region Input-Output (MRIO) Analysis which extends the analysis to global supply chains; and (3) Time-Series with Trade (TSTRD) calibrated to the EEBT. Their study found an increase in emission from the production of traded goods and services from 20% (4.3 Gt) to 26% (7.8 Gt) of global emissions. The net emission transfers from developing to developed countries increased from 0.4 Gt to 1.6 Gt in the same period, outgrowing the emissions reduction achieved through the Kyoto protocol. They found that developed countries consumption-based emissions increased faster than their territorial

Table 5: Most Frequently Locally Cited References within the Dataset

Author(S) And Year	Title	Journal	TC
(B. Meng et al., 2018)	Tracing CO2 Emissions in Global Value Chains	Energy Economics	20
(Koopman et al., 2014)	Tracing Value-Added and Double Counting in Gross Exports	American Economic Review	17
(Peters et al., 2011)	Growth in Emission Transfers via International Trade From 1990 To 2008	Proceedings of the National Academy of Sciences	17
(Peters et al., 2007)	China's Growing CO2 Emissions a Race Between Increasing Consumption and Efficiency Gains	Environmental Science & Technology	16
(Dietzenbacher et al., 2012)	Trade, Production Fragmentation, And China's Carbon Dioxide Emissions	Journal of Environmental Economics and Management	14
(Davis & Caldeira, 2010)	Consumption-Based Accounting of CO2 Emissions	Proceedings of the National Academy of Sciences	13
(Timmer Et Al., 2015)	An Illustrated User Guide to the World Input–Output Database: The Case of Global Automotive Production	Review of International Economics	12
(Antweiler Et Al., 2001)	Is Free Trade Good for the Environment?	American Economic Review	10
(Peters, 2008)	From Production-Based to Consumption-Based National Emission Inventories	Ecological Economics	10
(Grossman & Krueger, 1995)	Economic Growth and the Environment	The Quarterly Journal of Economics	9

Source: compiled by the author using data retrieved from Scopus and Web of Science

emissions, which means emissions are outsourced to developing countries. The paper also revealed regional shifts as developing countries are witnessing rapid growth in emissions, particularly for China.

(Peters et al., 2007) applied a structural decomposition analysis (SDA) based on input-output analysis to explore the drivers of China CO2 emissions between 1992 and 2002. They decompose the latter into four main drivers[10]. They found that GDP growth dominates the increase in emissions contributing with 129% in the period studied. Urbanization, Household Consumption and capital investments, especially in construction further exacerbates emissions. However, efficiency gains offset this increase by 62%. Net trade had marginal effects as emissions from exports are countered by emissions avoided through imports. The study identified potential under-reporting in coal consumption which has led to underestimation of emission growth.

(Dietzenbacher et al., 2012) examined China CO2 emissions linked to exports in 2002, highlighting the role of production fragmentation: the difference between processing exports and non-processing exports. They challenge prior research that neglects this distinction which may lead to significant overestimation of emissions. They employed a tripartite input-output (IO) model containing domestic production, processing exports, and non-processing exports. They show that prior estimates are over estimated by 60% and found that processing exports generate 34% less CO_2 per Yuan of value added than non-processing exports and account for 55% of exports but only 16.6% of export-related CO_2 emissions. The majority (87%) of China's emissions is driven by domestic consumption and non-processing exports.

In a similar vein; (Davis & Caldeira, 2010) were one of the pioneers of consumption-based accounting for CO2 emissions. The study employs a multiregional input-output (MRIO) model based in 2004 global economic data, disaggregated into 113 countries/regions and 57 industry sectors. They show how international trade embeds significant emissions, particularly from emerging markets like China to developed countries, as 23% of CO2 emissions in 2004 were traded internationally. They have identified net exporters and importers of emissions embodied in trade (EET). China (22.5% of its emissions were linked to consumption in other countries), Russia and the Middle East were the top net exporters. The USA and western Europe (countries like Switzerland, Sweden, and the U.K. imported >30% of their consumption-based emissions) were the top net importers of EET. They highlighted the carbon intensity of trade, and showed the disparities that exist between developed and developing economies.

(Timmer et al., 2015) serves as a user's guide to the World Input-Output Database (WIOD) which is a comprehensive and publicly available database that provides annual time series of world input-output tables. They outline the strengths and weakness of the databases, compared to other available databases. They showcase the robustness of the databases through an application on the automotive industry looking into production fragmentation, Regionalization and Globalization trends; income shifts; the impact of the financial crisis and China's rising role.

(Antweiler et al., 2001) aimed to explore the impact of free trade on the environment, specifically focusing on pollution concentrations. They developed a model that decomposes the effects of trade on pollution into three components: scale, technique, and composition effects[11]. Empirically, they used data on sulphur dioxide concentration from the Global Environment Monitoring System (GEMS) system across 43 countries from 1971 to 1996. They found that on average, freer trade reduces pollution concentrations, particularly through the technique

[10] GDP Growth (Consumption Volume); Efficiency Improvements, related to technological advancements; Production Structure; and Consumption Structure

- [11] Scale Effect: more economic activity leads to more pollution.
- Technique Effect: more income led to cleaner production methods and stricter environmental regulations.
- Composition Effect: Trade shifting production to more or less polluting industries depending on a country's comparative advantage.

effect, which outweighs the scale (very weak effect) and composition effects. This paper thus challenges the pollution haven hypothesis (PHH) and confirms the Environmental Kuznets Curve (EKC).

(Peters, 2008) explores the transition from production-based national emission inventories for emission accounting, to a consumption-based model in the context of climate policy. They highlight the limitation of the United Nations Framework Convention on Climate Change (UNFCCC) territorial system boundary which risks carbon leakage through imports. The author presents and compares two distinct models for constructing consumption-based National Emission Inventories (NEI). The first is the Emissions Embodied in Bilateral Trade (EEBT) which uses bilateral trade data to allocate emissions to exporting and importing countries without distinguishing between intermediate and final consumption. And the second is Multi-Regional Input–Output Analysis (MRIO) which splits bilateral trade into intermediate and final consumption, tracing emissions through global supply chains.

(Grossman & Krueger, 1995) looked into the relationship between economic growth and environmental quality (indicators include: urban air pollution, river oxygen levels, fecal contamination, heavy metal pollution) using panel data from the GEMS system. They found that economic growth impacts the environmental quality in an inverted U-shaped curve (the EKC).

3.2.2. Thematic and Conceptual Interpretation from Highly Cited Research

In this section we aim to develop a thematic and conceptual understanding of the reviews of the most cited articles for each period of the three periods we identified, as well as the most locally cited references. Each period was shaped by global policy shifts, methodological advancements and themes.

Looking into the reviews as a whole, we can deduce that research has moved from foundational to more applied research. The first period laid the theoretical and empirical foundations for understanding the intersection of GVCs, green finance and decarbonization. The main themes from the first period are carbon taxation, environmental economics, corporate carbon risk management, and sustainable supply chain management. It introduced key concepts and challenged others, such as (Goulder, 1995) challenged which prior first-economy modelling, and introduced the concepts of how carbon taxes can interact with pre-existing ones, revenue recycling and the double dividend hypothesis. While the paper didn't touch directly on GVC or green finance, its insights into the economic costs are very relevant. For example, tax interactions and revenue use has implications for designing carbon pricing mechanisms that minimize economic distortions while promoting decarbonization in global supply chains. (Huang et al., 2009) emphasized the importance of measuring indirect emissions in supply chains, which is crucial for accurately determining carbon footprints and accurate carbon accounting to inform investment decisions and carbon credit claims, highlighting the importance of addressing upstream emissions to achieve net-zero targets. (Busch & Hoffmann, 2007) integrated carbon risks into corporate risk management and looked into the financial implications of carbon constraints, thus highlighting the need for sustainable finance to support the transition to low-carbon economies. (L. Xu et al., 2013) identified external pressures driving green supply chain adoption which aligns with the growing institutional and market-driven push for decarbonization during this period. Lastly (Foran et al., 2005) integrating economic, social and environmental impacts into supply chain management using triple bottom line methodology, quantifying economic, social, and environmental impacts using a hybrid process-based LCA and IOA approach. It emphasizes the role of indirect effects and supply chain transparency. Econometrically, the papers in this first period mainly utilized dynamic general equilibrium models (Goulder, 1995), input-output analysis (Huang et al., 2009), and hybrid LCA-IOA approaches (Foran et al., 2005). These papers in the first period developed and introduced methodologies, concepts and findings which provided a basis for understanding how environmental and social impacts are embedded in global production networks, which is crucial for the later diversification and expansion of research in GVCs, green finance, and decarbonization.

Moving to the second period which saw the diversification of research driven by the Paris Agreement (2015), SDGs adoption, rise of ESG frameworks, and advances in data analytic. With a focus on integrating sustainability into logistics, supply chain cooperation, and policy-driven decarbonization strategies. The main theme from the research in the second period is sustainable logistics, green R&D cooperation, carbon tax impacts and closed-loop supply

chains. We observe the utilization of multi-objective optimization methodologies such as (Nurjanni et al., 2017; Soysal et al., 2014) which they use to try to balance between economics and environmental objectives in supply chains, evaluating trade-offs and challenging traditional economic based optimizations. This is especially relevant for cooperation aiming to achieve net-zero targets and comply with carbon regulations. Similarly (Fahimnia et al., 2015) utilized a bi-objective Mixed-Integer Nonlinear Programming (MINLP) model which integrates both economic and environmental objectives, solved through a modified cross-entropy method to examine trade-offs between economic efficiency and environmental performance under tax policies (Chen et al., 2019) bridged the gap between green supply chain management and technological innovation. The article is one of the first to simultaneously consider technological spillovers, power dynamics, and supply chain coordination in the context of green R&D. (Beretta & Hellweg, 2019) highlighted the environmental benefits of reducing food waste, aligning with SDG 12.3. thus, we can deduct from this period a more focus on policy, corporate management, and the utilization of more sophisticated econometric techniques; however, without the total abandonment of LCA and IOA.

The third period which saw an explosion of research activity thematically focused on carbon trading, sustainable energy sources, green technology investment. (Gao et al., 2020) looked into China ETS effectiveness using DID and DDD models combined with IOA making the study a key reference for policy evaluation in the field of carbon trading. The focus on carbon leakage and regional emissions transfers is directly relevant to discussions on decarbonizing GVCs. (Doliente et al., 2020) focused on looking into SAF and the aviation sector bridging in the meanwhile gaps between different fields, making it a valuable resource for researchers, policymakers, and industry stakeholders. It highlighted the importance of supply chain optimization, cross-border collaboration and resource sharing. It also explored the financial challenges of scaling up SAF calling for subsidies, incentives, and carbon pricing policies. Further, the study looked into the trade-offs that exists between economic efficiency and environmental impacts, in line with (Fahimnia et al., 2015; Nurjanni et al., 2017; Soysal et al., 2014). (Ma et al., 2021) integrates technology investment, government interventions and consumer preferences into a single framework providing a comprehensive dynamic model using differential game theory in order to address how supply chain actors can collaborate and invest in green technologies to achieve decarbonization goals. Finally (A. Liu et al., 2021) optimized location-inventory-routing models for perishable products, balancing economic costs and carbon emissions, utilizing YALMIP toolbox for solving multi-objective optimization. This period most cited research continues the trajectory established by the previous one, with a focus on developing models that integrate multiple factors, looking into the trade-offs between economic efficiency and environmental impacts and exploring practical decarbonization strategies.

As a whole the field developed from foundational to more applied research with an increasing complexity as early research focused on single themes, while later research integrated multiple objectives, and factors; as well as being more focused on policy and practical implications for governments and corporations. Methodologically, the field moved from theoretical modelling, to empirical optimization and finally into the use of advanced econometric and Cross-Disciplinary Tools

Looking into the most locally cited references which played a role in shaping the field (Koopman et al., 2014; B. Meng et al., 2018) provided methodological and conceptual foundations for understanding the environmental and economic impacts of GVCs by introducing emission and value added tracing in global trade. Prior work by (Antweiler et al., 2001) looked into the environmental impact of free trade and production fragmentation. (Davis & Caldeira, 2010; Peters, 2008; Peters et al., 2011) developed and established the importance of consumption-based emissions accounting and the role that global trade plays in global emissions. Crucial for understanding and designing better policies, instruments and strategies that address carbon leakages and push for sustainable GVCs. Similarly (Dietzenbacher et al., 2012) distinguished between processing exports and non-processing exports. (Timmer et al., 2015) introduced the WIOD database which represented a major development into data quality required to for such research.

3.3. Key contributors identified from the most prolific journals, authors, institutions, and countries

3.3.1. Journals

Table 6 (Panel A) highlights that the research discourse is dominated by high-impact energy and environmental economics journals. *Energy Economics* leads with 40 articles, followed by the *International Journal of Production Economics* (23) and *Energy Policy* (21). This distribution indicates that the research landscape is primarily framed through the lenses of energy systems modelling, production efficiency, and environmental policy. While specialized journals like *Resources, Conservation and Recycling* provide crucial sustainability perspectives, top-tier mainstream finance and banking journals are notably absent from the list. This reinforces the observation of a global "green finance blind spot," suggesting that the specific financial mechanisms for decarbonization are under-researched compared to the operational and regulatory aspects.

3.3.2. Authors

The authorship landscape is predominantly Chinese (Table 6, Panel B). The most prolific author, Li Xuetao (7 articles), focuses on supply chain digitization, carbon responsibility, and the determinants of carbon intensity. Other key contributors, such as Jiang Xuemei and Wang Ran (6 articles each), examine geographical shifts in GVC emissions and the carbon footprints of multinational enterprises. This concentration of authorship suggests a research agenda heavily influenced by the industrial and environmental priorities of the Chinese manufacturing sector.

3.3.3. Affiliations

Institutional leadership mirrors authorship trends, with the University of International Business and Economics (China) holding the top position with 14 articles (Table 6, Panel C). While Western institutions like

Table 6 Most prolific contributors by a number of articles

Panel A		Panel B		Panel C		Panel D	
Sources	Articles	Authors	Articles	affiliation	Articles	Country	Freq
Energy Economics	40	Li X	7	University Of International Business and Economics	14	China	265
International Journal of Production Economics	23	Jiang X	6	Capital Univ Econ and Business	13	Uk	63
Energy Policy	21	Li Y	6	Argonne National Laboratory	11	Usa	63
Resources, Conservation and Recycling	20	Wang R	6	Tianjin University	11	Germany	38
Ecological Economics	16	Wang J	5	Tsinghua University	10	Australia	34
Environment, Development and Sustainability	12	Wang X	5	Xiamen University	10	Spain	29
Structural Change and Economic Dynamics	10	Yan Y	5	Peking University	8	France	28
Frontiers In Energy Research	8	Zhang Z	5	Shanghai Jiao Tong University	8	Japan	25
Resources Policy	8	Wang F	4	Univ Oxford	7	Italy	22
Transportation Research Part E-Logistics and Transportation Review	8	Wang H	4	Karlsruhe Institute of Technology (Kit)	6	Switzerland	22

Source: generated by the author using data retrieved from Scopus and Web of Science (WoS)

the University of Oxford (UK) and Argonne National Laboratory (USA) remain significant contributors, the overwhelming prevalence of Chinese institutions reflects strong national strategic priorities, such as China's "dual carbon" targets and its active role in the global green bond market. This dominance presents a challenge for MENA

policymakers: the current evidence base is heavily skewed toward the industrial dynamics of a manufacturing superpower (China), potentially limiting its transferability to the resource-based or fragmented SME economies of the MENA region.

Table 7: Most relevant countries by corresponding authors

Country	Articles	Articles %	SCP[12]	MCP[13]	MCP %
China	97	32,7	73	24	24,7
United Kingdom	23	7,7	20	3	13
Usa	23	7,7	20	3	13
Germany	13	4,4	11	2	15,4
India	11	3,7	9	2	18,2
Italy	10	3,4	8	2	20
Spain	10	3,4	8	2	20
Switzerland	10	3,4	6	4	40
Australia	8	2,7	7	1	12,5
France	8	2,7	6	2	25

Source: generated by the author using data retrieved from Scopus and Web of Science (WoS)

3.3.4. Countries

Again, on this side China dominates in volume, it leads with 256 articles. As discussed above, this reflects a particular strategic interest in this research field. Western nations follow, as the UK and the USA tie for second place with 63 articles each, Germany (38), Australia (34), Spain (29), and France (28) round out the top contributors. However, there is a limited representation from Africa, Latin America, and the rest of Asia underscoring a research imbalance potentially overlooking localized challenges. Similarly, China accounts for 32.7% of corresponding-author articles. This shows research leadership, which means it is driving the research agenda. With an MCP of 24.7% - which indicates international collaboration – higher than most western nations indicate Chinese engagement in global research networks.

Table 8: Top 10 Countries by Total Citations and Average Citations per Article

Country	TC	Average Article Citations
China	2178	22,50
Usa	839	36,50
United Kingdom	640	27,80
Switzerland	564	56,40
Germany	292	22,50
Australia	269	33,60
Netherlands	265	53,00
Italy	243	24,30
Canada	207	29,60
Portugal	192	48,00

Source: generated by the author using data retrieved from Scopus and Web of Science (WoS)

However, despite Chinese dominance in volume, its influence doesn't follow the same trend. It leads in total citations (2,178) but have lower average citations (22.5) than all the other top 10 contributors by citations, signalling high output but moderate per-article impact. While, on the other hand, western nations excel in impact. This disparity may be driven journal preferences, collaboration networks, and research focus.

this concentration poses a specific risk for MENA policymakers: elasticities and transition pathways derived from China's unique state-capitalist industrial model may not hold true for the fragmented, SME-heavy economies of the Middle East. Relying on this 'imported wisdom' without local validation could lead to significant policy miscalculations.

4. Science Mapping

4.1. Co-citation analysis

co-citation analysis (CCA) gives us the opportunity to look at the foundational knowledge and the intellectual structure that the dataset is based upon. In a co-citation analysis cluster emerges based on how frequently papers are cited together. We run a co-citation analysis using Vos viewer, full counting with 5 minimum citations as a threshold. We looked for duplicate entries, but didn't find any. The results reveal 4 clusters made out of 91 papers (9 papers were orphans). Table 9 shows the most relevant papers from each cluster, ranked by their total link strength. The

[12] SCP : single country publication

[13] MCP : multiple countries publication

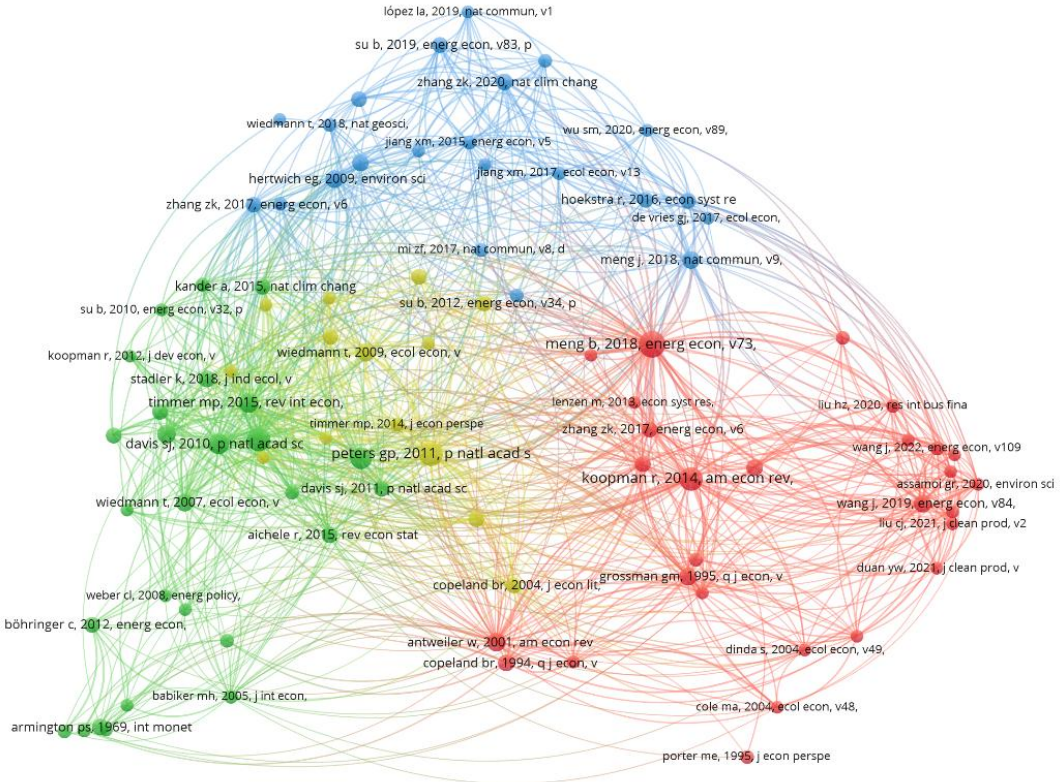
resulting co-citation network is visualized in Figure 2. The four clusters identified represent a distinct conceptual focus while also interlocking with one another.

4.1.1. Co-citation Cluster 1: GVCs, Trade and environmental outcomes

cluster 1 (in red) shown in Figure 2 is the biggest cluster and the main focus of this cluster is GVCs, trade, and their environmental impact. With emphasis on tracing emissions, the pollution hypothesis, and the Kuznets curve. The two most influential papers in this cluster focus on tracing CO2 Emissions in Global Trade Network. The corner stone of this cluster the paper by (B. Meng et al., 2018) in which the authors introduce a unified framework to systematically trace CO2 emissions and value-added in GVCs, highlighting how cross-border production sharing affects the environmental costs and their redistribution. The second most relevant paper in this cluster (Koopman et al., 2014) complements it by providing an accounting framework that bridges trade statistics and national accounts for breaking down trade into value-added components which identifies double counting issues in exports, critical for accurate emission tracing in GVCs.

Further, this cluster contains 3 highly relevant seminal works on the Economic Growth, Trade, and Environmental Impact nexus. One of which (Antweiler et al., 2001) is the third most influential paper in this cluster. Combined, they provide significant theoretical contributions, and argue that while trade can increase emissions initially, economic development can eventually lead to better environmental outcomes. (Antweiler et al., 2001) is a seminal paper that introduces the scale, technique, and composition effects of trade on pollution providing a theoretical basis for understanding how trade liberalization can both increase and decrease emissions, depending on the interplay of these effects. (Grossman & Krueger, 1995) introduces the EKC which argues that environmental degradation initially worsens with income growth but eventually improves. (Copeland & Taylor, 1994) looked into north-south trade developing a model which showed how high-income countries outsource pollution intensive production to low-income nations providing the theoretical basis for the PHH.

Figure 2 Nomological network of co-citations



Source: generated by the author using data retrieved from Scopus and Web of Science (WoS).

More recently, several papers in this cluster dealt with the problem of how international trade and economic integration affect environmental outcomes, particularly through the PHH. (López et al., 2013), and (Z. Zhang et al., 2017a) analysed the PHH and how trade specialization leads to shifts in emissions between countries, with evidence from Spain, China relations, and multi-regional input-output analyses.

This cluster also contains recent empirical studies looking at the EKC. (J. Wang et al., 2019, 2022) explored the dynamic relationship between GVC participation, economic growth, and emissions. They suggest that while deeper integration into GVCs initially increases emissions, in the long run, GVC participation can drive sustainable growth through improved efficiency and technological upgrading. The study by (H. Liu et al., 2020) further supports this by examining China's manufacturing sector, showing that China's position in GVCs affects its export-related emissions, with the GVC effects outweigh scale, composition, and technique effects. Upgrading within GVCs could help reduce carbon intensity. Echoing a version of the EKC.

Overall, this cluster captures a crucial debate about how globalization and trade integration influence the environment. The dominant perspective is that while trade and GVCs contribute to worsened environments through emissions due to scale effects and trade-driven pollution shifting, long-term economic development and structural transformations will lead to a reduction in emissions through improved production techniques and green innovation. The studies collectively suggest that policy interventions, such as R&D investment and stricter environmental regulations, and better emission accounting are necessary to mitigate the environmental costs of global trade.

4.1.2. Co-citation Cluster 2: Carbon Accounting and Carbon leakage

In this cluster the emphasis shifts towards the effects of accounting methods on reported emissions, carbon leakage distinguishing between processing and normal exports, and proposals for improved carbon accounting. The main theme within this cluster is the transition from production-based to consumption-based emission inventories which reassigns responsibility, influencing discussions on international climate agreements and environmental justice. A more detailed examination of this cluster reveals the first key theme which is CO2 emissions embodied in trade. The most influential and central paper in this cluster is (Peters & Hertwich, 2008) with 69 links and 180 total link strength, a foundational paper which quantifies emissions embodied in trade finding over 5.3 Gt of CO2 is embodied in global trade with Annexe B countries of the Kyoto protocol as net importers. It highlights how trade flows can negatively affect global climate policies, and argues for adjustments in emission inventories for better climate policy. Similarly (Davis & Caldeira, 2010) with 66 links and 157 total link strength, estimates the 23% of global CO2 emissions are traded globally, thus highlighting the role trade is playing in redistributing emissions. The authors call for shared responsibility between producers and consumers. Their subsequent study (Davis et al., 2011) expands on this by tracing emissions along the full supply chain finding that 37% of global CO2 emissions are linked to the trade of fossil fuels.

Building on these discussions another critical theme in this cluster examines the distinction between processing and normal exports in emissions accounting (Dietzenbacher et al., 2012) the second most important paper and the most linked, addressed the biases found in traditional emission estimates and presented a methodological breakthrough by making the aforementioned distinction. Using a tripartite input-output table, they found that emissions from Chinese exports would be overestimated by 60% if no distinction is made. Thus, demonstrating that ignoring production fragmentation leads to inaccurate assessments of emissions. Reinforcing this finding (Su et al., 2013) showed that traditional models overestimate emissions and that processing exports have lower CO2 impacts.

Recognizing these challenges, several studies advocate for improved carbon accounting methods. For instance (Peters, 2008) discuss and advocates for a transition towards consumption-based national emission inventories instead of the traditional production-based inventories in order to prevent carbon leakage and promoting shared responsibility. (Kander et al., 2015) proposed a refined technology-adjusted consumption-based accounting method that credits countries for cleaner export industries. (Wiedmann et al., 2007) Reviews multi-region input–output

models for assessing trade-embedded emissions and calling for the need for a more detailed sectoral and regional data to accurately estimate emissions embodied in trade.

A final critical theme in this cluster concerns GVCs. (Hummels et al., 2001) document the phenomena of vertical specialization, showing that 21% of OECD exports involve imported inputs making emission allocation complex providing early evidence of production fragmentation, a key driver of carbon leakage and embodied emissions. This work on production fragmentation frames much of the subsequent research on emissions in global value chains. (Timmer et al., 2015) explain the construction and the application of the WIOD database, key for multi-region input-output analysis enabling further detailed analysis of global value chains and emissions. With 62 links and 119 total link strength, this methodological contribution has been highly influential.

Overall, this cluster mainly calls for moving away from production-based accounting (used in the Kyoto protocol) which leads to carbon leakage, and move towards consumption-based accounting which can provide a more accurate and equitable assessment. Furthermore, not distinguishing between processing exports and normal exports can lead to inaccurate assessments of co2 emissions. Finally, trade specialization and GVCs require better emissions tracking methodologies to ensure better accountability and better climate policies. *Throughout the cluster, there is a clear progression from identifying the issue of emissions embodied in trade, to quantifying its scale, to developing more sophisticated methodologies for accurate accounting, and finally to proposing policy innovations that could better align climate governance with the reality of globally fragmented production.

4.1.3. Co-citation Cluster 3: Emissions Embodiment in Complex Supply Chains and Multidimensional Responsibility

cluster 3 conceptual focus is on the Geographic Shifts in GVCs and Carbon Relocation. Meaning, emission redistribution through GVC reconfiguration and multinational enterprise (MNE) activities. This cluster zooms in on production sharing and the role of intermediate goods in emission embedding. It also looks into the value-added contributions and the carbon footprints of nations and multinational enterprises. The uniqueness of this cluster comes from its focus on analysing spatial redistribution of emissions, which is distinct from Cluster 1's that establishes the general nexus between trade and emissions.

The most influential paper in this cluster looks at the carbon footprints and trade linked emissions. (Hertwich & Peters, 2009) presents a global and trade-linked analysis of GHG emissions focusing on household consumption patterns, mobility and food as primary sources to assess the nation's carbon footprint. The authors found great heterogeneity between countries, as low as 1 tCO2e/y in African countries to as high as ~30t/y in Luxembourg and the United States. For GHG they found an Expenditure Elasticity of 0.57, for CO2 the cross-national Expenditure Elasticity is 0.81 which is very similar within individual countries as well and holds true across very large differences in income and emissions. Briefly, as nations and households (which account for 72% of global GHG emissions) spends more, they emit more GHG. this study highlights the importance of consumption-based accounting and the problem of emission redistribution. Delving deeper into cross-border dynamics; (Z. Zhang et al., 2017b) analysed the effects of production fragmentation across borders on carbon footprints and their implications for border carbon adjustment. The authors introduced the concept of border-crossing frequency as a way for better assessing carbon footprint instead of only looking at size and composition, linking it to the spatial accounting of emissions and policy design. The authors examined what happens if the U.S. imposes carbon tariffs on emissions embedded in imported goods and found that China will bear the biggest financial burden. As border crossing frequency is rising, this may cause the problem of multiple taxation along the supply chain creating a challenge in fairly distributing the tax burden.

Focusing more on south-south trade and emission redistribution. (J. Meng et al., 2018) document the rise of south-south trade and production reallocation from China to other developing nations. Emphasizing the shift of energy-intensive production from China to less developed countries such as Vietnam and Bangladesh. The ever more complex nature of global supply chains is "distributing energy-intensive industries and their CO2 emissions throughout the global South" which will undermine international efforts for decarbonization. Similarly (Jiang &

Green, 2017) aimed to study the shift in the geography of Global Supply Chains from developed to developing nations, and also from China, to less developed nations; and its effects on GHG emissions. due to the gap in energy efficiency and low-carbon technology, they found significant increases in GHG emissions both from direct and indirect effects. (Hoekstra et al., 2016) studied the effects of international sourcing on emissions and found that it increases emissions in low-wage countries and decreased them in high-wage countries. (Su & Thomson, 2016) applied input-output models to China's exports distinguishing between normal and processing exports identifying key drivers of embodied carbon emissions. Highlighting the role of structural changes in production and trade in shaping emission trends.

(Z. Wang et al., 2017) aimed to propose a solution for these problems developing two novel indices to better measure GVCs participation. They provide a framework that categorizes total production activities at different levels to different types 1. domestic, traditional international trade, Simple GVCs, Complex GVCs. The two indices developed: Forward-Linkage-Based GVC Participation Index and a Backward-Linkage-Based GVC Participation Index. This will avoid double accounting and provides Perspective Flexibility. GVC reconfiguration also implicates MNE. (Z. Zhang et al., 2020) looked into the embodied carbon emissions in the MNE supply chain, proposing an investment-based accounting method for better emissions responsibility and allocating emissions to the investing country. Similarly (Jiang et al., 2015) highlights the role of foreign-invested enterprises in China's export-related emissions showing that they contribute more to emissions than Chinese-owned enterprises. This study highlights the conflict between national and global interests in reducing emissions, particularly in the context of FDI and the responsibility debate. Lastly, (Miller & Blair, 2009, p. 2) provide foundational textbooks on input-output analysis and offers a comprehensive framework for analysing the environmental impacts of economic activities widely, used in carbon emissions research

This cluster conceptually focus on responsibility attribution mechanisms for the emissions from a globalized production network. Several approaches emerge: consumption-based attribution, investment-based attribution and ownership-based attribution. Furthermore, this cluster introduces new analytical tools for understanding emissions such as border-crossing frequencies, Structural Decomposition Analysis, Forward-Linkage-Based GVC Participation Index and a Backward-Linkage-Based GVC Participation Index. Virtually all the papers on this cluster use input-output techniques.

4.1.4. Co-Citation Cluster 4: Methodological and Analytical Frameworks for Tracing Emissions in Fragmented Global Production

This cluster can be conceptually understood as a bridge cluster which is evident when looking at the top 10 papers in this cluster as well as its position in between the first 3 clusters. The 4th cluster appears to be about developing methodological and analytical approaches to trace, measure, and understand emissions and the current nature of global value chains. As such, the distinguishing feature of Cluster 4 from the other 3 clusters is its meta-analytical approach as it's primarily about the methods and frameworks of analysis themselves, rather than the substantive findings or practical implications find in the other clusters. This makes this cluster methodologically reflexive as it provides the methods and frameworks of research itself, providing the analytical toolkit that enables the insights in the other clusters.

The papers in this cluster can be categorized in three categories. the ones that are dealing with emissions embodied in trade; papers that provide broader context and methodological papers. Several papers in this cluster highlight how international trade has contributed to the growth in global CO2 emissions. (Peters et al., 2011) showed how international trade is responsible for the global emissions increase. The authors looked into why emissions in developing countries (non-Annexe B) have doubled and found that emissions from the production of traded goods and services have increased, and most developed countries have increased their consumption-based emissions faster than their territorial emissions. The net emission transfers via international trade from developing to developed countries increased from 0.4 Gt CO2 in 1990 to 1.6 Gt CO2 in 2008, which exceeds the Kyoto Protocol emission reductions. This paper is not only the most influential paper in this cluster but also the second most influential paper

in the whole map, and it is the most centrally positioned paper in the co-citation map. Aiming for answering the same question (Malik & Lan, 2016) utilized an SDA to analyse the global trends in outsourcing of emissions, identifying "outsource" countries. In a similar vein (Y. Xu & Dietzenbacher, 2014) utilized SDA in order to explore emissions embodied in trade between 40 countries, showing that emissions from imports grew faster than emissions from exports in developed countries. A key reason for this finding is the change in the structure of trade, both in intermediate and in final products. They found an increase of emissions embodied in imports for developed countries and an increase of emissions embodied in exports for emerging countries. Alternatively (Feng et al., 2013) looked into interprovincial emission outsourcing and carbon leakage within China, showing that these dynamics can also occur within nations.

The second set of papers in this cluster provides the general framework and context for this research filed. A central paper in the whole co-citation map and the second most in this cluster is (Copeland & Taylor, 2004) reviewing the environmental impacts of international trade and economic growth, including both the PHH and the EKC from a theoretical and empirical standpoint.

Focusing more on GVC Architecture and the mechanisms of an increasingly fragmented global production; (Timmer et al., 2014) Explores the international fragmentation of production utilizing decomposition techniques and focusing on manufacturing goods to gain an understanding of the state of the global fragmentation of production which will provide a starting point for further analysis. The authors showing trends in the increasing role of advanced economies in high-skilled labour-intensive activities and emerging economies in capital-intensive activities. (Johnson & Noguera, 2012) examines how production sharing across borders affects trade measurements by comparing gross trade flows with value-added trade flows. It highlights the distortions caused by intermediate goods trade in traditional trade statistics. The authors found that value-added exports are generally smaller than gross exports, particularly for manufacturing exports due to high intermediate input usage. The ratio is generally lower for richer countries, which means they engage more in production sharing. The authors also found that Accounting for export processing in China and Mexico further reduces their value-added export ratios, emphasizing their role as assembly hubs. This is another central paper to the whole map due to providing a clearer picture of global trade by addressing double-counting in gross trade statistics and revealing the true economic contributions of countries in global supply chains.

The third set of papers in this cluster deals with methodological issues, with a particular focus on SDA which is used more often in this cluster than the other ones. SDA was the main focus of this study (Su & Ang, 2012) which compares structural decomposition analysis (SDA) and index decomposition analysis (IDA) in energy and emission studies, emphasizing the usefulness of SDA in understanding the driving forces of emissions changes. Alternatively (Su & Ang, 2013) compares two different approaches for calculating emissions in a country's imports. The first - competitive import - assumes imports compete directly with domestic products and the second -non-competitive imports treats imports separately from domestic production. The study finds that using the competitive import assumption results in higher CO_2 estimates than the non-competitive approach. The key difference arises from how China's imported emissions for intermediate goods are transferred into China's export emissions, which explains why recent studies report high CO_2 emissions for China's exports. While (Wiedmann, 2009) provides a review of multi-region input-output model used for consumption-based emission accounting and calls for improvements in data availability and accuracy in MRIO models.

Cluster 4 consolidates critical evidence, frameworks, and methods that enable research across the other clusters. It documents the empirical reality of emission outsourcing, provides tools for consumption-based accounting, and clarifies GVC fragmentation.

Table 9: Key Co-Cited References per Cluster by TLS[14]

[14] Total Link Strength

Item Type	Publication Year	Author(s)	Title	Journal/Source	Links	Total link strength	Citations
Cluster 1: Trade, GVCs, and Environmental Outcomes							
journal Article	2018	Meng, Bo; Peters, Glen P.; Wang, Zhi; Li, Meng	Tracing CO2 emissions in global value chains	Energy Economics	81	247	20
journal Article	2014	Koopman, Robert; Wang, Zhi; Wei, Shang-Jin	Tracing Value-Added and Double Counting in Gross Exports	American Economic Review	75	179	17
journal Article	2001	Antweiler, Werner; Copeland, Brian R; Taylor, M. Scott	Is Free Trade Good for the Environment?	American Economic Review	61	109	10
journal Article	2019	Wang, Jing; Wan, Guanghua; Wang, Chen	Participation in GVCs and CO2 emissions	Energy Economics	42	97	9
journal Article	2013	López, Luis Antonio; Arce, Guadalupe; Zafrilla, Jorge Enrique	Parcelling virtual carbon in the pollution haven hypothesis	Energy Economics	56	95	7
journal Article	2017	Zhang, Zengkai; Zhu, Kunfu; Hewings, Geoffrey J.D.	A multi-regional input–output analysis of the pollution haven hypothesis from the perspective of global production fragmentation	Energy Economics	57	94	7
journal Article	1995	Grossman, G. M.; Krueger, A. B.	Economic Growth and the Environment	The Quarterly Journal of Economics	49	93	9
journal Article	2022	Wang, Jing; Rickman, Dan S.; Yu, Yihua	Dynamics between global value chain participation, CO2 emissions, and economic growth: Evidence from a panel vector autoregression model	Energy Economics	38	72	6
journal Article	1994	Copeland, B. R.; Taylor, M. S.	North-South Trade and the Environment	The Quarterly Journal of Economics	46	68	8
journal Article	2020	Liu, Huizheng; Zong, Zhe; Hynes, Kate; De Bruyne, Karolien	Can China reduce the carbon emissions of its manufacturing exports by moving up the global value chain?	Research in International Business and Finance	37	67	6
Cluster 2: Carbon Accounting and Carbon leakage							
journal Article	2008	Peters, Glen P.; Hertwich, Edgar G.	CO₂ Embodied in International Trade with Implications for Global Climate Policy	Environmental Science & Technology	69	180	16
journal Article	2012	Dietzenbacher, Erik; Pei, Jiansuo; Yang, Cuihong	Trade, production fragmentation, and China's carbon dioxide emissions	Journal of Environmental Economics and Management	77	161	14
journal Article	2010	Davis, Steven J.; Caldeira, Ken	Consumption-based accounting of CO₂ emissions	Proceedings of the National Academy of Sciences	66	157	13
journal Article	2015	Timmer, Marcel P.; Dietzenbacher, Erik; Los, Bart; Stehrer, Robert; De Vries, Gaaitzen J.	An Illustrated User Guide to the World Input–Output Database: The Case of Global Automotive Production	Review of International Economics	62	119	12
journal Article	2008	Peters, Glen P.	From production-based to consumption-based national emission inventories	Ecological Economics	52	103	10
journal Article	2007	Wiedmann, Thomas; Lenzen, Manfred; Turner, Karen; Barrett, John	Examining the global environmental impact of regional consumption activities; Part 2: Review of input–output models for the assessment of environmental impacts embodied in trade	Ecological Economics	51	96	9
journal Article	2001	Hummels, David; Ishii, Jun; Yi, Kei-Mu	The nature and growth of vertical specialization in world trade	Journal of International Economics	53	85	6
journal Article	2015	Kander, Astrid; Jiborn, Magnus; Moran, Daniel D.; Wiedmann, Thomas O.	National greenhouse-gas accounting for effective climate policy on international trade	Nature Climate Change	49	83	7
journal Article	2011	Davis, Steven J.; Peters, Glen P.; Caldeira, Ken	The supply chain of CO₂ emissions	Proceedings of the National Academy of Sciences	51	81	7
journal Article	2013	Su, Bin; Ang, B.W.; Low, Melissa	Input–output analysis of CO2 emissions embodied in trade and the driving forces: Processing and normal exports	Ecological Economics	42	71	6

Cluster 3: Emissions Embodiment in Complex Supply Chains and Multidimensional Responsibility							
journal Article	2009	Hertwich, Edgar G.; Peters, Glen P.	Carbon Footprint of Nations: A Global, Trade-Linked Analysis	Environmental Science & Technology	61	112	9
journal Article	2018	Meng, Jing; Mi, Zhifu; Guan, Dabo; Li, Jiashuo; Tao, Shu; Li, Yuan; Feng, Kuishuang; Liu, Junfeng; Liu, Zhu; Wang, Xuejun; Zhang, Qiang; Davis, Steven J.	The rise of South–South trade and its effect on global CO2 emissions	Nature Communications	56	100	9
journal Article	2017	Zhang, Zengkai; Zhu, Kunfu; Hewings, Geoffrey J.D.	The effects of border-crossing frequencies associated with carbon footprints on border carbon adjustments	Energy Economics	53	92	7
journal Article	2020	Zhang, Zengkai; Guan, Dabo; Wang, Ran; Meng, Jing; Zheng, Heran; Zhu, Kunfu; Du, Huibin	Embodied carbon emissions in the supply chains of multinational enterprises	Nature Climate Change	45	88	8
journal Article	2016	Hoekstra, Rutger; Michel, Bernhard; Suh, Sangwon	The emission cost of international sourcing: using structural decomposition analysis to calculate the contribution of international sourcing to CO₂ -emission growth	Economic Systems Research	52	82	7
report	2017	Wang, Zhi; Wei, Shang-Jin; Yu, Xinding; Zhu, Kunfu	Measures of Participation in Global Value Chains and Global Business Cycles	NBER	48	80	7
journal Article	2015	Jiang, Xuemei; Guan, Dabo; Zhang, Jin; Zhu, Kunfu; Green, Christopher	Firm ownership, China's export related emissions, and the responsibility issue	Energy Economics	48	77	6
journal Article	2017	Jiang, Xuemei; Green, Christopher	The Impact on Global Greenhouse Gas Emissions of Geographic Shifts in Global Supply Chains	Ecological Economics	45	72	6
journal Article	2016	Su, Bin; Thomson, Elspeth	China's carbon emissions embodied in (normal and processing) exports and their driving forces, 2006–2012	Energy Economics	45	67	5
book	2009	Miller, Ronald E.; Blair, Peter D.	Input-Output Analysis: Foundations and Extensions	Publisher: Cambridge University Press	38	63	8
Cluster 4 Methodological and Analytical Frameworks for Tracing Emissions in Fragmented Global Production							
journal Article	2011	Peters, Glen P.; Minx, Jan C.; Weber, Christopher L.; Edenhofer, Ottmar	Growth in emission transfers via international trade from 1990 to 2008	Proceedings of the National Academy of Sciences	79	202	17
journal Article	2004	Copeland, Brian R; Taylor, M. Scott	Trade, Growth, and the Environment	Journal of Economic Literature	55	96	7
journal Article	2012	Johnson, Robert C.; Noguera, Guillermo	Accounting for intermediates: Production sharing and trade in value added	Journal of International Economics	57	94	7
journal Article	2009	Wiedmann, Thomas	A review of recent multi-region input–output models used for consumption-based emission and resource accounting	Ecological Economics	55	94	9
journal Article	2013	Feng, Kuishuang; Davis, Steven J.; Sun, Laixiang; Li, Xin; Guan, Dabo; Liu, Weidong; Liu, Zhu; Hubacek, Klaus	Outsourcing CO₂ within China	Proceedings of the National Academy of Sciences	49	85	7
journal Article	2014	Timmer, Marcel P.; Erumban, Abdul Azeez; Los, Bart; Stehrer, Robert; De Vries, Gaaitzen J.	Slicing Up Global Value Chains	Journal of Economic Perspectives	52	83	6
journal Article	2012	Su, Bin; Ang, B.W.	Structural decomposition analysis applied to energy and emissions: Some methodological developments	Energy Economics	53	78	7
journal Article	2016	Malik, Arunima; Lan, Jun	The role of outsourcing in driving global carbon emissions	Economic Systems Research	46	69	5
journal Article	2014	Xu, Yan; Dietzenbacher, Erik	A structural decomposition analysis of the emissions embodied in trade	Ecological Economics	48	65	7
journal Article	2013	Su, Bin; Ang, B.W.	Input–output analysis of CO2 emissions embodied in trade: Competitive versus non-competitive imports	Energy Policy	38	60	5

Source: generated by the author using data retrieved from Scopus and Web of Science (WoS)

4.2. Keyword co-occurrence analysis

Keyword co-occurrence analysis is a bibliometric technique that shifts the focus from publications to the actual content and themes embedded within the research. It explores the thematic structure of the field by analysing how keywords appear together (co-occur) across publications, thereby revealing conceptual relationships (Donthu et al., 2021). As such, keywords form clusters that represent distinct research themes or intellectual subfields. These clusters help map the conceptual landscape of research at the intersection of global value chains, green finance, and decarbonization.

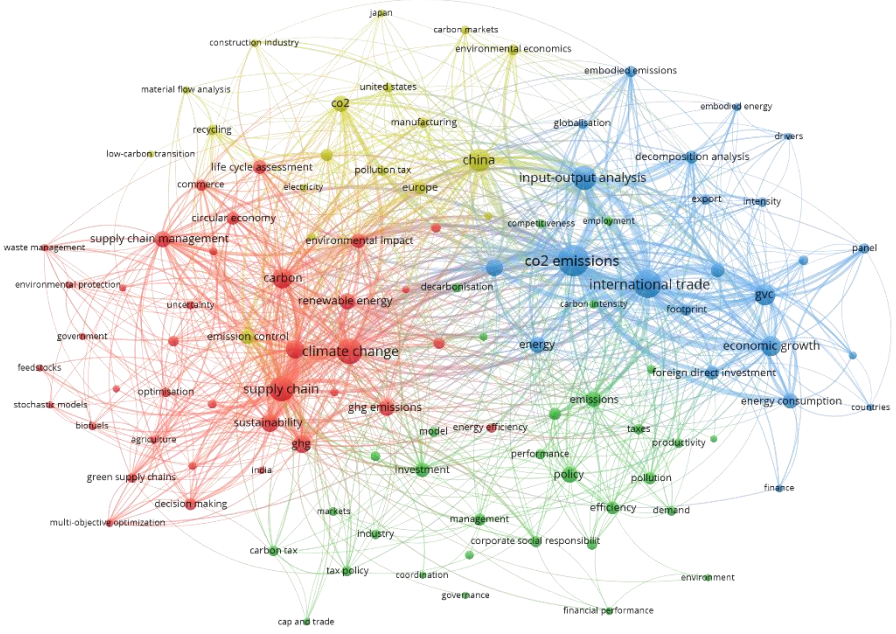
For this analysis, we employed VOSviewer software due to its robust visualization capabilities and clustering algorithms. We developed a comprehensive thesaurus file to standardize terminology as shown in Figure 6 in Appendices. We set the minimum occurrence threshold at 5 appearances in the dataset. This process yielded 110 unique keywords distributed across four distinct thematic clusters. Table 10 lists the top keywords defining each cluster based on network links. the descriptive statistics of metrics are presented in Table 13 in the Appendices. The resulting visualization in Figure 3 provides valuable insights into how research themes interconnect, their relative importance based on occurrence frequency, and their temporal evolution. We will analyse each cluster separately and then draw conclusions.

Figure 4 provides a specific visualization of the network coloured by the average publication year of the keywords, highlighting emerging and foundational themes.

4.2.1. Keyword co-occurrence Cluster 1: Operational Sustainability and Environmental Management in Supply Chains

This cluster represents the core operational nexus of the field, linking "Supply chain," "Climate change," and "Carbon" with high-impact concepts like "Green supply chains" and "multi-objective optimization," which achieve

Figure 3 Nomological network of keyword co-occurrence



Source: generated by the author using data retrieved from Scopus and Web of Science (WoS).

the highest citation metrics. "Environmental regulation" serves as a critical bridge node connecting these operational concerns to the broader network. The cluster reveals three distinct research fronts: an energy transition focus with recently emerging keywords like "Renewable energy" and "Biofuels"; a strong methodological emphasis on "Life Cycle Assessment (LCA)" and "Multi-objective optimization," with "Uncertainty" emerging recently to reflect a shift

toward resilience; and a sectoral concentration on "Agriculture" alongside rapidly growing themes like "Waste management" and "Circular economy," indicating a strategic move toward closed-loop supply chain models.

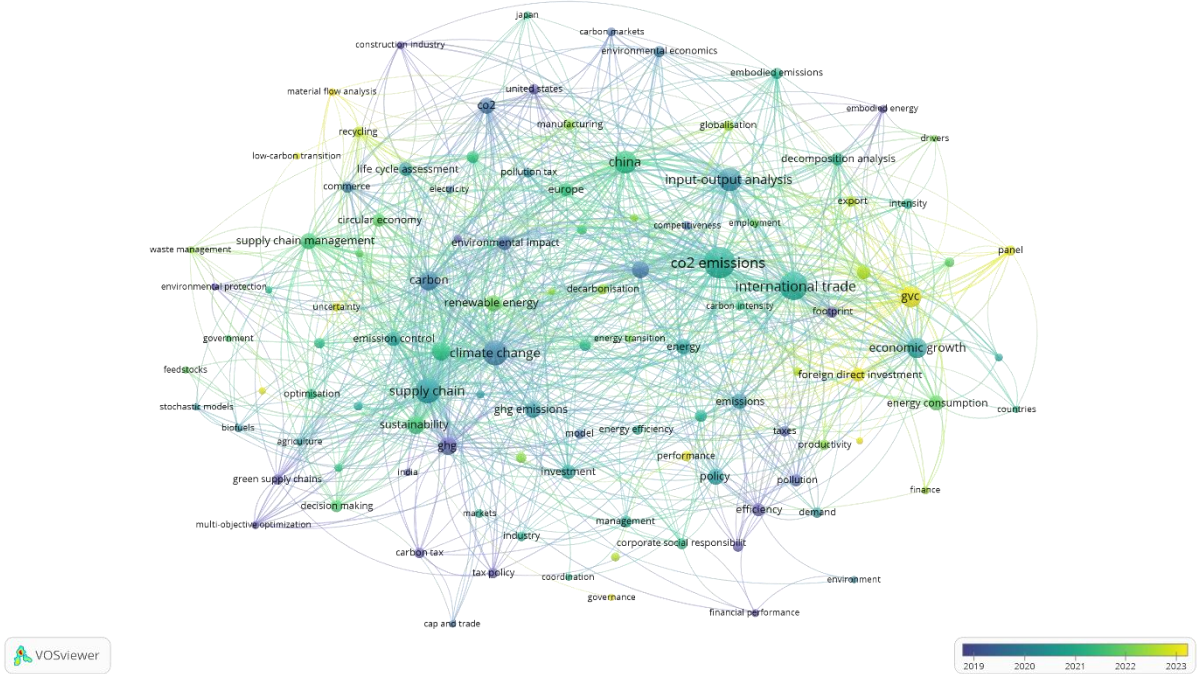
4.2.2. Keyword co-occurrence Cluster 2: Economic Policy Instruments and Business Response to Emissions

Characterized by a diffuse network structure rather than a single dominant node, this cluster examines the intersection of regulatory instruments and industrial behaviour. "Decarbonization" acts as a critical bridge connecting this policy-focused cluster to the broader network. The thematic analysis reveals a "Policy-Performance Nexus," linking market-based instruments (e.g., "Carbon tax," "Cap and trade") to economic outcomes (e.g., "Efficiency," "Productivity," "Competitiveness"). While terms like "Financial performance" represent the field's foundational roots, the emergence of keywords like "Governance" (avg. year 2023.6) and "Corporate Social Responsibility" indicates a shift toward institutional arrangements. Notably, the high citation impact of "Investment" (48.5 average citations) underscores the central role of financial flows in translating these regulatory frameworks into actual industrial change.

4.2.3. Keyword co-occurrence Cluster 3: Quantifying Emissions Embodied in Trade and Global Value Chains

This cluster serves as the quantitative backbone of the network, featuring the highest connectivity and density of links. It centres on "CO2 emissions" (81 occurrences) and "International trade," bridged by the concept of "Carbon footprint." The thematic structure is defined by a strong reliance on "Input-output analysis" and "Decomposition analysis" as foundational methodologies to measure "Embodied emissions" and trace the "Trade-Energy-Growth" nexus. Theoretical anchors like the Environmental Kuznets Curve and Pollution Haven Hypothesis connect these metrics to broader economic development debates. Crucially, while "GVC" is a central, highly relevant keyword, the terms "Finance" and "Foreign Direct Investment" appear as a distinct, recently emerging (avg. year >2022) but statistically peripheral sub-group. This temporal lag confirms that while the *measurement* of GVC emissions is mature, the integration of *financial mechanisms* remains a nascent frontier in the literature.

Figure 4 keyword co-occurrence network by average publication year



Source: generated by the author using data retrieved from Scopus and Web of Science (WoS)

4.2.4. Keyword co-occurrence Cluster 4: Geographical and Sectoral Dimensions of Emission Control

This cluster provides the spatial and industrial context of the field, anchored by "China" (43 occurrences, 92 links) as the central node, reflecting its pivotal role in global manufacturing emissions. While China dominates in volume, the analysis of normalized citations reveals that research focused on the "United States" and "Europe" achieves higher relative impact. Thematically, the cluster traces an evolution in carbon management from specific market mechanisms like "Carbon markets" (avg. year 2019.4) to broader systemic approaches like "Low-carbon transition" (avg. year 2022.8). Sectorally, the focus is on heavy emitters like "Manufacturing" and "Construction," while the high impact and recency of "Recycling" (avg. year 2022.5) signal a critical methodological convergence between GVC decarbonization and circular economy frameworks such as "Material flow analysis."

4.2.5. Emerging Patterns and Gaps in the Conceptual Structure

Cross-cluster analysis reveals deep structural distinctness in how the field approaches decarbonization. Sectorally, a clear dichotomy exists between the biological, upstream focus of agriculture (Cluster 1) and the industrial, downstream focus of manufacturing (Cluster 4). This fragmentation extends to methodology, where product-level industrial ecology tools (LCA) remain distinct from macro-level economic structural analysis (IOA). Policy research is similarly siloed, treating operational compliance, market mechanisms, and geographic implementation as separate spheres rather than a unified framework. Most critically, the analysis empirically confirms the "green finance blind spot." Despite the dataset's focus, specific instruments like "green bonds" or "sustainability-linked loans" are virtually absent from the network. While generic "finance" terms appear as a nascent, peripheral theme (Cluster 3), they lack integration with core GVC operations, indicating that while the *measurement* of emissions is well-developed, the *financial mechanisms* to mitigate them remain a largely unexplored frontier.

Table 10 Top 10 Keywords per Cluster by number of links

label	Links	Total link strength	Occurrences	Avg. pub. year	Avg. citations	Avg. norm. citations
Cluster 1: Operational Sustainability and Environmental Management in Supply Chains						
supply chain	88	316	52	2020,37	39,4	1,4534
climate change	88	313	53	2019,79	40,5	1,402
carbon	80	234	33	2019,76	41,0	1,1737
sustainable development	74	204	30	2021,3	39,3	2,0558
ghg	73	190	26	2019,08	54,9	2,019
supply chain management	70	192	22	2021,5	35,1	1,8323
sustainability	69	187	26	2021,5	36,8	1,8985
ghg emissions	66	134	23	2020,17	32,0	1,1324
renewable energy	60	129	23	2021,87	12,4	0,73
environmental impact	59	130	18	2019,5	47,0	1,2667
Cluster 2: Economic Policy Instruments and Business Response to Emissions						
investment	65	122	18	2020,61	48,6	1,8424
emissions	55	119	20	2020,1	25,1	0,8965
policy	49	90	22	2020,45	36,0	1,0905
efficiency	48	76	14	2017,79	38,2	1,02
industry	47	55	8	2020,88	68,9	2,1457
emission reduction	40	53	9	2022,11	41,3	1,7276
carbon leakage	40	75	13	2020,85	17,8	0,8261

management	37	57	12	2020,75	25,6	0,7495
tax policy	37	59	10	2017	63,3	0,9397
performance	35	46	10	2022,9	12,4	0,693
Cluster 3: Quantifying Emissions Embodied in Trade and Global Value Chains						
co2 emissions	97	516	81	2020,84	27,9	1,0765
international trade	89	398	65	2020,8	23,8	0,9682
carbon footprint	81	197	25	2019,64	44,4	1,3165
input-output analysis	74	275	47	2020,06	23,8	0,723
GVCs	62	202	36	2022,86	11,9	0,7707
energy	61	141	21	2020,52	27,8	0,923
economic growth	60	199	35	2020,46	28,1	0,9407
foreign direct investment	50	107	17	2022,94	14,4	1,1313
consumption	44	97	16	2022,44	16,3	0,9916
energy consumption	43	114	20	2021,8	24,8	0,9719
Cluster 4: Geographical and Sectoral Dimensions of Emission Control						
China	92	299	43	2021,28	24,1	1,0842
co2	65	158	22	2019,59	57,1	1,8637
environmental policy	57	98	13	2021,38	30,3	1,3955
emission control	57	132	18	2020,67	47,2	1,6287
Europe	51	94	14	2021,36	41,4	1,5763
united states	50	81	9	2017,56	54,7	1,1069
recycling	43	78	10	2022,5	26,1	2,5966
environmental economics	42	80	11	2019,82	37,5	1,0946
manufacturing	41	69	10	2022,2	36,3	2,4995
technology	41	47	6	2022,17	17,3	0,6383

Source: generated by the author using data retrieved from Scopus and Web of Science (WoS)

4.3. Analysis of MENA-Focused Research: Identifying the Gap

The initial regional search yielded a total of 12 unique documents. As this sample size is methodologically insufficient for quantitative bibliometric mapping, a qualitative content analysis was conducted to determine the thematic focus and relevance of each document to the intersection of GVCs, finance, and decarbonization in the MENA region.

The analysis reveals that the "green finance blind spot" identified in the global dataset becomes a near-total research void when applied to the MENA region. The documents fall into three distinct categories. The first category includes geographically relevant but thematically mismatched papers. These are four articles with a genuine research focus on the MENA region, yet none address the financing of GVC decarbonization. (Perry, 2020) examines the Argan oil value chain in Morocco but focuses on social sustainability and women's empowerment rather than financial mechanisms. (Alshebami, 2021) investigates "green banking" in Saudi Arabia, but analyses it through a marketing lens regarding corporate image. (Khalilnezhad & Eslamloueyan, 2025) discuss the macroeconomic impact of oil shocks in the MENA region, focusing on fiscal policy rather than private sector supply chain finance. Finally, (H. Zhang, 2021) provides a comparative analysis including the Middle East, but restricts the scope to regulatory frameworks for Carbon Capture (CCUS), not financial instruments.

The second category are geographically mismatched (False Positives) and includes six articles which were captured by the search query due to tangential mentions of regional terms but are substantively focused elsewhere. For example, (Li et al., 2020) focus on Sino-US trade, mentioning the Middle East only as an upstream energy source. Other studies focus on agricultural technologies in China (Du et al., 2024), humanitarian supply chains in Nepal and Peru (Handler et al., 2025), or farm productivity in Germany (Wettemann, 2017).

The remaining documents include a publisher's erratum and a general management book chapter (Howarth et al., 2023) that lists Qatar among global business networks but offers no regional empirical analysis.

In summary, while the global analysis in Sections 3.1 and 3.2 identified a lack of focus on financial instruments, this sub-sample analysis confirms that for the MENA region specifically, the evidence base is virtually non-existent. There is currently no peer-reviewed literature addressing the specific financial mechanisms required to decarbonize the region's industrial global value chains.

5. Proposed Research Agenda: Bridging the Gap Between Metrics and Mechanisms

Triangulating the findings from our global performance analysis, science mapping, and regional review reveals a clear structural convergence: the field is anchored in measurement, not finance. The co-citation clusters focusing on carbon accounting correspond directly to the keyword clusters regarding "quantifying emissions," where foundational concepts like "Input-Output Analysis" and "Carbon footprint" dominate. Yet, despite the inclusion of finance terms in our search query, specific instruments like "green bonds" or "sustainability-linked loans" are either absent or not as significant.

This "Green Finance Blind Spot" is exacerbated by geographic asymmetry. The global dominance of Chinese institutions (Cluster 4) means that current transition models are based on the industrial dynamics of a manufacturing superpower. For the MENA region, this creates a double-bind: policymakers face the same macro-level threats (CBAM, export vulnerability) identified in the global literature, but lack both the financial research and the localized evidence base to respond.

Consequently, simply replicating global studies is insufficient. The region does not need more diagnostic research; it needs a targeted inquiry into the financial architecture of transition. We propose a research agenda structured around five pillars, designed to move the field from diagnosing the carbon problem to funding its solution.

5.1. The Regional State of Knowledge

While our global bibliometric analysis revealed a structural deficit in green finance research, a targeted review of regional scholarship and "grey literature" indicates that the components of this challenge are being analysed in isolation. By synthesizing insights from different studies, we can reconstruct the current state of knowledge regarding GVCs and decarbonization in the MENA region.

Existing regional literature focuses heavily GVC Participation, trade integration and Environmental Outcomes rather than its financing. (Yanikkaya et al., 2022) utilize a global dataset to demonstrate that developed nations effectively outsource greenhouse gas (GHG) emissions to developing regions, a finding corroborated by (Moussir, 2024), who reports that increased GVC integration in Morocco has historically driven up CO2 emissions through backward linkages. Crucially, (Guedidi & Baghdadi, 2020) find that Regional Trade Agreements (RTAs) with strong environmental provisions significantly reduce pollution in MENA's low-tech sectors. value chain positions matter: while upstream, low-tech manufacturing tends to drive pollution, participation in downstream or backward linkages significantly lowers emissions through technology transfer. Similarly, (Siewers et al., 2024) and (Elmassah & Hassanein, 2023) provide firm-level evidence that GVC participation can induce the adoption of greener technologies (the "Porter Hypothesis"), provided that strong domestic institutions and regulations are in place. Furthermore, the literature identifies a shift from merely 'greening' existing sectors to creating entirely new value chains. Recent reports highlight that countries like Morocco, the UAE, and Jordan are positioned to leverage renewable resources to build 'green ecosystems,' exporting high-value green hydrogen and ammonia rather than just raw commodities (Tanchum, 2024) . However, this transition is not automatic. (Elmassah & Hassanein, 2023) warn that increased digitalization, often viewed as a green enabler, can actually offset environmental gains by driving up energy consumption unless complemented by robust policy frameworks.

The transition from voluntary greening to mandatory compliance is a dominant theme in recent policy work. The economic risks of the EU's Carbon Border Adjustment Mechanism (CBAM) have been rigorously diagnosed. (Acar et al., 2021) provide a first-order estimate for Turkey, projecting that CBAM could impose an annual cost of EUR 1.1–1.8 billion on Turkish exporters. while these studies successfully quantify the macroeconomic cost of inaction, they stop short of analysing the micro-financial mechanisms required to fund the necessary industrial retrofitting. Adding to the urgency, (Martínez-Zarzoso et al., 2024) argue that without legally enforceable environmental clauses in trade agreements, the region risks attracting 'footloose' polluting industries seeking to evade stricter regulations elsewhere. The implications of these trade shocks extend beyond the balance of payments to sovereign solvency. (Agarwala et al., 2021) argue that for MENA economies, the 'transition risk' of global decarbonization poses a direct threat to fiscal sustainability. As export revenues in carbon-intensive sectors decline, sovereign borrowing costs may rise, creating a feedback loop that constrains the state's ability to fund the very green infrastructure required to mitigate the CBAM threat

A review of the financial literature reveals a stark dichotomy between sovereign achievements and private sector constraints. At the macro level, the region is making strides. (Lamby et al., 2023) highlight the UAE's Sustainable Finance Framework and the rapid growth of green bond portfolios, while the World Bank's assessment of Egypt's 2020 sovereign green bond (Hussain, 2022) confirms high investor appetite for regional climate assets. Work by (Naeem et al., 2023) on GCC markets further suggests that green bonds offer valuable diversification benefits for regional investors.

However, this liquidity is not reaching the industrial base. The (Ragab & Medhat, 2025) explicitly identifies "limited access to climate finance" as a primary barrier for Micro, Small, and Medium Enterprises (MSMEs) in the energy transition. This is corroborated by the World Economic Forum (Alami & Goodman, 2024) and UNEP Finance Initiative (Scaling Private Sector Climate Finance in the MENA Region, 2022), which report that while banks have set high-level climate targets, they lack the operational frameworks to lend to SMEs for decarbonization. The barrier is not merely risk aversion, but a scarcity of 'commercially viable' or 'bankable' projects presented by smaller firms, particularly for decentralized renewable energy integration. This creates a structural choke point because

multinational buyers are increasingly focused on 'Scope 3' emissions which include their suppliers' logistics and transport. (Alami & Goodman, 2024) warn that without financing for clean transport and logistics, entire MENA value chains risk being cut off from global markets. The literature thus describes a "missing middle": capital is available for sovereign mega-projects but inaccessible for the GVC suppliers who face the CBAM threat. This capital gap is not merely a local hurdle but a structural vulnerability for GVC participation. Since up to 90% of a product's emissions often lie in the supply chain ('Scope 3 emissions'), multinational buyers are increasingly mandating decarbonization from their Tier 2 and Tier 3 suppliers (Alami & Goodman, 2024). Consequently, the inability of MENA banks to operationalize SME climate lending creates a bottleneck that threatens to decouple the region's industrial base from global buyers who can no longer afford 'dirty' supply chains.

Finally, the literature points to a unique regional opportunity that remains theoretically recognized but operationally underexplored. (Héla Miniaoui, 2023) suggests that wealthier MENA nations could leverage climate finance mechanisms to support regional adaptation. (UNDP, 2025) report confirm the growth of the Green Sukuk market, yet note that issuances are almost exclusively sovereign or quasi-sovereign. There is a conspicuous absence of academic or policy work on structuring Islamic financial products such as *Musharakah* or *Ijarah*, specifically for industrial decarbonization, representing a significant gap in the literature.

5.2. GVC Reconfiguration Under Decarbonisation

The first pillar addresses the urgent need to understand how global decarbonisation policies are reshaping the comparative advantage of MENA economies. While existing studies explore GVC participation and carbon intensity, there remains a critical empirical void regarding how emerging climate-related trade measures such as the EU's Carbon Border Adjustment Mechanism (CBAM), US clean-tech subsidies (under the Inflation Reduction Act also introduce friend-shoring incentives that may reroute investment toward politically aligned economies, affecting MENA export prospects in renewables, batteries, and green hydrogen), and the growing rollout of Scope 3 disclosure requirements (e.g., under the EU Corporate Sustainability Reporting Directive CSRD). These measures will reallocate production across borders. Research in this area must move beyond static risk assessments to map dynamic sectoral exposures, identifying which industries face the highest probability of GVC exclusion. This is particularly acute for the region's carbon-intensive tradable sectors, such as iron, steel, aluminium, fertilizers, and cement, which are central to North African and Gulf economies. Beyond defence, scholars should investigate whether the region's abundance of low-carbon energy resources can be leveraged to create new GVC niches in green materials production, shifting from a fuel-based to a low-carbon comparative advantage. Empirical research should therefore quantify the conditions under which access to low-cost solar, wind, and green hydrogen could support near-shoring of intermediate processing stages such as green aluminium smelting, synthetic ammonia production, or low-carbon steel.

To provide robust evidence for these shifts, the research community must adopt advanced methodological approaches. We propose the construction of a MENA-wide GVC Carbon Exposure Index that combines export data with process-level carbon intensities. Furthermore, scholars should utilize Multi-Regional Input-Output (MRIO) models integrated with climate-policy elasticity parameters to simulate trade flow changes under different carbon pricing scenarios. MRIO models should also be paired with structural gravity models that incorporate carbon-adjusted trade costs to improve robustness. This would allow researchers to estimate substitution elasticities across suppliers under different carbon regimes. Causal inference techniques, such as synthetic control methods, should be employed to project the specific effects of CBAM implementation on national exports and sectoral employment. For instance, Morocco's fertilizer sector and the UAE's aluminium exports already exhibit significant CBAM-linked exposure due to high embedded carbon intensities relative to EU benchmarks. This work is essential to provide policymakers with the foresight needed to navigate the structural transformation of the region's trade relationships.

5.3. The Micro-Foundations of SME Green Finance

The second pillar targets the "missing middle" of the transition: the Micro, Small, and Medium Enterprises (MSMEs) that constitute over 90% of the private sector in MENA economies yet remain largely excluded from climate finance flows. Gray literature confirms a financing gap estimated between $210–300 billion, depending on inclusion of informality and micro-enterprise categories in the region, but academic research has yet to quantify the share of this gap specifically related to green upgrades. A robust research agenda must investigate the micro-foundations of this market failure, examining why regional commercial banks struggle to underwrite decarbonization loans. Structural barriers such as weak credit information systems, high collateral requirements, and short loan maturities appear incompatible with the long-term nature of decarbonisation investments, yet these constraints have not been empirically tested in the context of green finance. Moreover, informality exceeding 50% in parts of North Africa poses an additional challenge: many SMEs operate outside the formal financial system altogether, limiting eligibility for any green lending instruments.

To harness the potential of private enterprise, future research must rigorously analyse both the supply and demand sides of this equation. On the supply side, researchers should employ discrete-choice modelling to estimate how banks price transition risk and determine whether they assign specific risk premiums to decarbonisation loans. Researchers should also test whether internal bank taxonomies classify decarbonisation investments as 'asset-light,' thereby increasing capital charges under Basel III/IV standards, a hypothesis that remains untested in the MENA context. On the demand side, studies must assess the technical capacity of SMEs to generate "bankable" projects, specifically quantifying the knowledge deficit around Monitoring, Reporting, and Verification (MRV) protocols. Survey experiments could be used to measure SMEs' willingness to adopt MRV tools when paired with various financial incentives such as interest rate reductions, guarantee coverage, or audit vouchers. Crucially, the agenda should move toward interventionist research, designing and testing prototype blended-finance structures; such as first-loss tranches or climate-risk guarantees; to determine which mechanisms most effectively lower the cost of capital. Randomized evaluations of SME green audit interventions could further isolate the impact of technical assistance on credit access, providing the evidence base needed to transform the region's banking sector from a barrier into an enabler of the green transition.

5.4. Green Finance as a Competitiveness Mechanism

The third pillar seeks to move beyond the availability of capital to establish the causal link between financial access and industrial upgrading. While the literature suggests a positive correlation between environmental performance and financial resilience, there is currently no empirical evidence within the MENA region on whether access to green finance instruments such as sustainability-linked loans or green bonds, actually influences a firm's ability to join or upgrade within Global Value Chains. Research in this area is critical to determine if financial incentives can effectively drive compliance with the increasingly stringent environmental requirements of lead firms, such as ISO 14001 certification or detailed Scope 3 emissions reporting. Several lead firms in textiles, automotive, and electronics have already begun embedding supplier-level emissions thresholds into procurement contracts creating a measurable 'GVC compliance premium' that remains undocumented in MENA. Furthermore, scholars must investigate the potential bidirectional causality of this relationship: does deep integration into high-value GVCs act as a signalling mechanism that attracts green capital, and conversely, does access to lower-cost green capital allow firms to capture higher value-added segments of the chain?

To provide policymakers with evidence on the returns to green investment, methodological rigor is essential. Future studies should prioritize firm-level econometric analysis, utilizing techniques such as Difference-in-Differences (DiD) designs around green-capital eligibility reforms to isolate causal effects. Where policy reforms are staggered across countries (e.g., Jordan, Morocco, UAE), generalized DiD estimators (Sun & Abraham 2020) can correct for heterogeneous treatment timing. Event studies examining stock market or export performance following green bond issuances could quantify the "green premium" for regional firms. Event studies could, for example, examine OCP Group's sustainability-linked financing activities or the UAE's Masdar bond issuances to evaluate market reactions

to green capital mobilization. Additionally, employing matching techniques to link firm-level emissions data with trade performance would allow researchers to measure whether "greened" firms face reduced non-tariff barriers in climate-sensitive sectors, providing a powerful economic argument for the private sector to lead the transition. Combining firm-level emissions datasets with customs microdata would allow for matching-based identification of whether greener firms face shorter export-clearance times or fewer non-tariff barrier checks.

5.5. Islamic Finance Innovation for Industrial Decarbonization

The fourth pillar explores the untapped potential of the region's distinct financial architecture to solve the capital cost problem. Our review of grey literature indicates a structural paradox: while the Green Sukuk market is expanding rapidly in the Gulf and Southeast Asia, issuance remains heavily concentrated in sovereign debt and mega-infrastructure projects, creating a disconnect with the "real economy" needs of industrial supply chains. The asset-backed nature of Islamic finance is theoretically well-suited for industrial decarbonization. Specifically, for financing tangible assets like energy-efficient machinery or on-site solar generation. Yet it remains underutilized for this purpose. Research is urgently needed to bridge this gap by designing and evaluating Islamic financial products specifically tailored for Scope 1 and 2 emission abatement in the manufacturing sector.

Scholars should focus on financial engineering to adapt specific instruments for the SME context. For instance, research should model the cash-flow implications of *Ijarah* (leasing) structures, which could allow firms to upgrade technology without heavy upfront capital expenditure, versus *Musharakah* (partnership) models that allow banks to share the risk and return of energy savings. For example, an Ijarah model could finance industrial heat pumps or variable-speed drives, where monthly lease payments are benchmarked against verified energy savings. A Musharakah model could be used to co-finance solar PV installations in industrial estates, with profit-sharing tied to metered electricity output. Methodologically, this requires moving beyond theoretical discussions to quantitative cash-flow modelling and partial-equilibrium simulations. Researchers should verify whether these instruments can effectively lower the cost of capital compared to conventional debt and identify the specific regulatory bottlenecks between Sharia governance boards and climate-finance taxonomies that currently hinder their deployment in the industrial sector.

5.6. Institutional Frameworks and Taxonomy Harmonization

The fifth pillar addresses the regulatory infrastructure required to mobilize international capital and de-risk private investment. The OECD and World Bank have identified the lack of a harmonized regional green taxonomy as a critical barrier, creating "greenwashing" risks that repel high-quality Foreign Direct Investment (FDI). Consequently, a comprehensive research agenda must focus on the technical and institutional design of a MENA Green Taxonomy. Research efforts should aim to define robust technical screening criteria for key regional sectors such as petrochemicals, fertilizers, and desalination, that are often excluded from standard European taxonomies but are essential for the regional transition. Additionally, scholars should engage in comparative policy analysis to determine how a regional taxonomy can achieve interoperability with the EU's framework while reflecting local economic realities. Research should also assess the feasibility of transitional activity categories that allow high-emission sectors to qualify for financing under tightening criteria, mirroring approaches used in the ASEAN taxonomy. Understanding the institutional role of central banks in enforcing these standards and the impact of mandatory disclosure requirements on capital flows will be essential for creating a trusted environment for global climate investors. Methodologies such as Delphi studies involving regional regulators and comparative case studies of taxonomy implementation in similar emerging markets will be crucial to designing a framework that crowds in, rather than restricts, private investment. Additionally, agent-based modelling could explore how banks, investors, and firms adjust behaviour under competing taxonomy scenarios.

5.7. Climate Vulnerability and GVC Resilience

Finally, a distinct MENA-specific pillar must address the physical realities of the region: extreme water scarcity and heat stress. While global GVC literature focuses heavily on carbon mitigation, regional research must also tackle adaptation and resilience. Industrial zones in North Africa and the Gulf are highly water- and energy-intensive, making them vulnerable to climate shocks that could disrupt supply chain continuity. Research in this area should assess firm-level exposure to physical climate risks and evaluate how these vulnerabilities affect export reliability and insurance costs. Scholars should investigate whether investments in adaptation technologies, such as desalination powered by renewable energy or heat-resistant infrastructure, can be financed through "resilience bonds" or similar instruments. By employing spatial climate-economics modelling and supplier-buyer emission-intensity mapping, researchers can provide the data needed to price physical risk into GVC finance, ensuring that the region's industrial base remains resilient in a warming world.

6. Conclusion and policy implications

Guided by the SPAR-4-SLR protocol, our analysis of 297 documents (1995–2025) maps a research field that has expanded exponentially (15.78% annual growth) but unevenly. The performance analysis reveals a landscape heavily dominated by Chinese institutions and energy economics journals, creating a geographic asymmetry that limits the immediate transferability of findings to the MENA context. Structurally, the science mapping identifies a clear intellectual trajectory: the field has matured from foundational trade-environment theory (Cluster 1) to sophisticated consumption-based accounting and carbon leakage methodologies (Cluster 2). However, despite the search query's explicit focus, the analysis empirically confirms the structural absence of a dedicated finance cluster. Terms related to "green finance" appear only as peripheral nodes in the keyword network, disconnected from the core operational research on Global Value Chains.

This bibliometric analysis reveals a critical characteristic of the current research landscape: the field is robust in diagnostics; employing sophisticated tools like MRIO, LCA, and SDA; but critically underdeveloped regarding financial instruments. The dominant clusters identified; GVC-environment linkages and decarbonization accounting; operate in isolation from the peripheral themes of general investment and policy. This structural disconnect creates a dangerous policy gap for the MENA region, where the industrial base is dominated by SMEs integrated into global supply chains. Governments and financiers possess the risk narratives regarding CBAM exposure and embodied emissions, yet they lack the implementable financing mechanisms to translate that knowledge into investment and competitiveness.

By triangulating these bibliometric results with a qualitative review of regional grey literature, this study identifies and defines the "Green Finance Blind Spot." While global academia provides robust diagnostic tools (MRIO, LCA) to measure emissions, and regional grey literature quantifies the macro-risk of CBAM, neither stream addresses the financial mechanisms required for industrial adaptation. To address this void, this paper proposes a targeted Research Agenda that moves beyond general recommendations to offer specific methodological pathways; from using Difference-in-Differences to measure green premiums, to cash-flow modelling of Islamic financial instruments. This agenda serves as a blueprint for closing the gap between the region's diagnostic capacity and its financial implementation needs.

To bridge the divide between identifying climate risks and financing the necessary industrial transition, regional stakeholders must shift their focus from measurement to mobilization through a coordinated policy response across three strategic horizons:

In the immediate term (Regulatory Enablement), the priority must be to enable the regulatory environment by resolving the information asymmetries that currently block green capital flows. Securities regulators and ministries of industry should mandate phased corporate climate disclosure for export-oriented firms, beginning with Scope 1 and 2 reporting for lead firms. To prevent these requirements from becoming a barrier to entry for smaller suppliers,

policymakers should pilot subsidized green audit vouchers to lower technical costs and develop lender-facing MRV (Monitoring, Reporting, and Verification) tools. Concurrently, regional bodies must collaborate to develop an interoperable MENA Green Taxonomy. By aligning with international frameworks such as the EU Taxonomy while providing region-specific technical screening for critical sectors like desalination, petrochemicals, and heavy industry, the region can reduce greenwashing risks and enable international investors to benchmark assets with confidence.

In the medium term (Capital Mobilization), the focus must shift to financial engineering. To overcome the scarcity of bankable projects among SMEs, development banks and sovereign wealth funds should launch targeted blended-finance facilities. By utilizing first-loss tranches and guarantees, these facilities can de-risk commercial lending for energy-efficiency retrofits. Furthermore, the region possesses a unique comparative advantage in Islamic Finance that remains underutilized for industrial decarbonization. Central banks and Sharia boards should promote the piloting of asset-backed instruments; specifically, Ijarah to circumvent collateral shortages for green equipment and Musharakah for shared-risk retrofitting; to expand the investor base and lower the cost of capital for the real economy.

In the long term (Institutional Integration), climate risk management must be integrated into the core mandates of financial and economic institutions. Export Credit Agencies (ECAs) should institutionalize supplier-level finance windows, linking export support to decarbonization plans to maintain access to carbon-sensitive markets. Simultaneously, central banks must integrate climate risk into banking supervision through stress-testing portfolios with significant industrial exposure. By offering tiered capital treatment for verified green loans, regulators can align incentives across the banking sector.

For the academic community, these findings imply a need to move beyond diagnostic carbon accounting. Future research must embrace interdisciplinary approaches that fuse supply chain modelling with financial econometrics, testing which liquidity mechanisms best drive decarbonization in emerging markets.

These findings should be interpreted within the context of standard bibliometric limitations, including potential coverage bias from relying on Scopus and Web of Science, which may exclude non-indexed grey literature, and the static nature of citation metrics which can lag behind rapid policy developments.

Ultimately, the evidence is clear, the MENA region possesses the measurement capacity to diagnose its GVC carbon exposure but lacks the financial architecture to address it. A passive reliance on global solutions is insufficient given the specificities of the region's SME-heavy industrial structure. By executing a combined strategy of harmonized taxonomies, targeted blended finance, and Islamic financial innovation, regional policymakers can convert the risk of carbon border adjustments into a catalyst for industrial upgrading, securing the region's position in the future global economy.

7. Appendices

Table 11 Search query string uses in Scopus and WOS

Panel A: Scopus

(TITLE-ABS-KEY ("Global Value Chain*" OR "GVC*" OR "Backward Linkage*" OR "Forward Linkage*" OR "outsourc*" OR "Vertical Specialization" OR (("Good*" OR "Input*") AND "Intermedia*") OR (("Global" OR "International" OR "Cross-border") AND ("Production Network*" OR "supply chain*" OR "value chain*" OR "Supply Network*" OR "Sourcing")))
AND TITLE-ABS-KEY (("Green" OR "clean" OR "low carbon" OR "climate" OR "ESG" OR "Renewable*" OR "Sustainabl*" OR "Environment*") AND ("financ*" OR "invest*" OR "bond*" OR "bank*" OR "tax*" OR ("Fund*" AND NOT "Fundamental") OR "capital" OR "credit*" OR "loan*" OR "insurance" OR "stock*" OR "equit*" OR "asset*"))
AND TITLE-ABS-KEY ("Decarboni?ation" OR "Carbon" OR "carbon dioxide" OR "CO2" OR "GHG" OR "Greenhouse Ga*" OR "Green house Ga*" OR "net zero" OR "Zero Emission" OR "carbon neutral*" OR "emission reduction"))

Panel B: WOS

TS=(("Global Value Chain*" OR GVC* OR "Backward Linkage*" OR "Forward Linkage*" OR outsourc* OR "Vertical Specialization" OR ((Good* OR Input*) AND Intermedia*) OR ((Global OR International OR "Cross-border") AND ("Production Network*" OR "supply chain*" OR "value chain*" OR "Supply Network*" OR Sourcing))))
AND
TS=((Green OR clean OR "low carbon" OR climate OR ESG OR Renewable* OR Sustainabl* OR Environment*) AND (financ* OR invest* OR bond* OR bank* OR tax* OR (Fund* NOT Fundamental) OR capital OR credit* OR loan* OR insurance OR stock* OR equit* OR asset*))
AND
TS=(Decarboni?ation OR Carbon OR "carbon dioxide" OR CO2 OR GHG OR "Greenhouse Ga*" OR "Green house Ga*" OR "net zero" OR "Zero Emission" OR "carbon neutral*" OR "emission reduction")

Panel C: The Added Boolean Operator to Target Middle East Specific Documents

AND (Turkey OR Turkiye OR Iran* OR Egypt* OR Jordan* OR Lebanon OR Lebanese OR Tunisia* OR Morocco* OR Algeria* OR Syria* OR Iraq* OR Sudan* OR Libya* OR Yemen* OR "Saudi Arabia" OR Saudi OR Qatar* OR Kuwait* OR Bahrain* OR Oman* OR Palestine* OR "United Arab Emirates" OR UAE OR "Emirates" OR MENA OR "Middle East" OR "North Africa" OR Arab*)

Table 12: overview of the Initial Scopus and Web of Science Datasets (Post-Filtering)

Panel A Scopus dataset

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	1995:2025
Sources (Journals, Books, etc)	90
Documents	220
Annual Growth Rate %	14,89% (8,93)
Document Average Age	4,69
Average citations per doc	24,99
References	12373
DOCUMENT CONTENTS	
Keywords Plus (ID)	1463
Author's Keywords (DE)	894
AUTHORS	
Authors	630
Authors of single-authored docs	32
AUTHORS COLLABORATION	
Single-authored docs	34
Co-Authors per Doc	3,27
International co-authorships %	35
DOCUMENT TYPES	
article	214
review	6

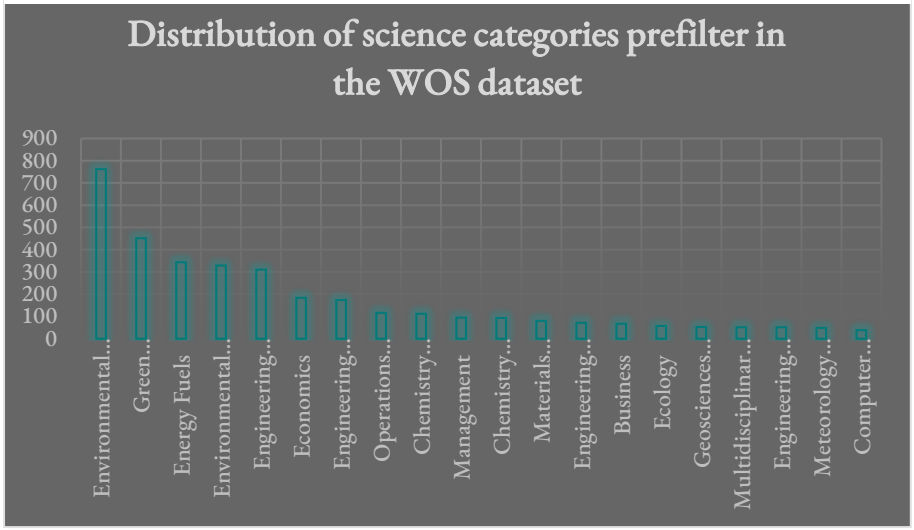
Panel B Web of science dataset

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	1995:2025
Sources (Journals, Books, etc)	69
Documents	173
Annual Growth Rate %	13.26% (8.64)
Document Average Age	5,09
Average citations per doc	21,57
References	9542
DOCUMENT CONTENTS	
Keywords Plus (ID)	523
Author's Keywords (DE)	694
AUTHORS	
Authors	467
Authors of single-authored docs	27
AUTHORS COLLABORATION	
Single-authored docs	28
Co-Authors per Doc	3,12
International co-authorships %	31,79
DOCUMENT TYPES	
article	157
article; book chapter	1
article; early access	9
article; proceedings paper	3
review	3

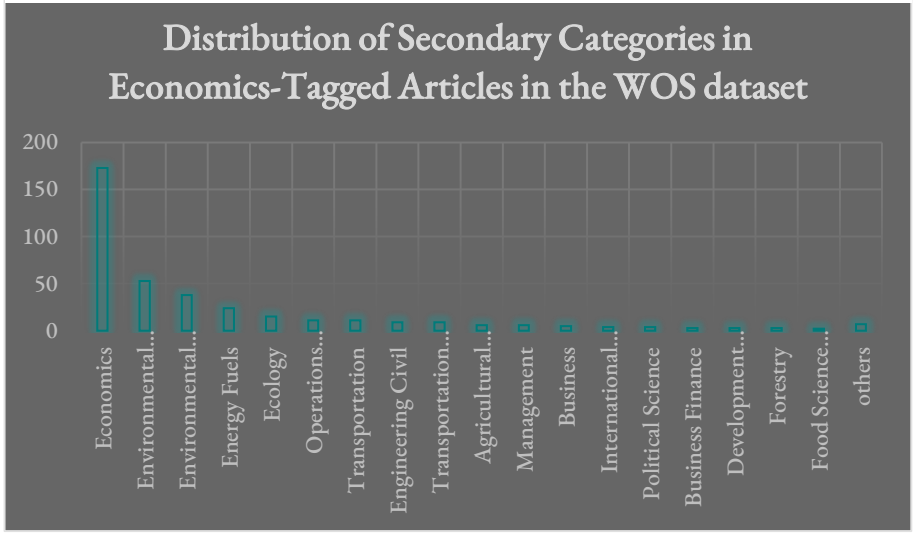
Source: generated by the author using data retrieved from Scopus and Web of Science (WoS)

Figure 5 distribution of science categories pre and post filter in the Scopus and WOS dataset

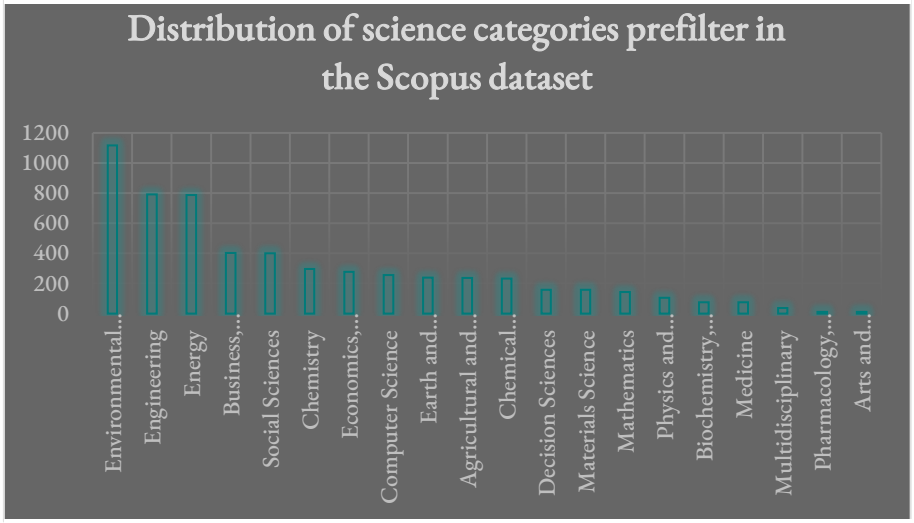
Panel A



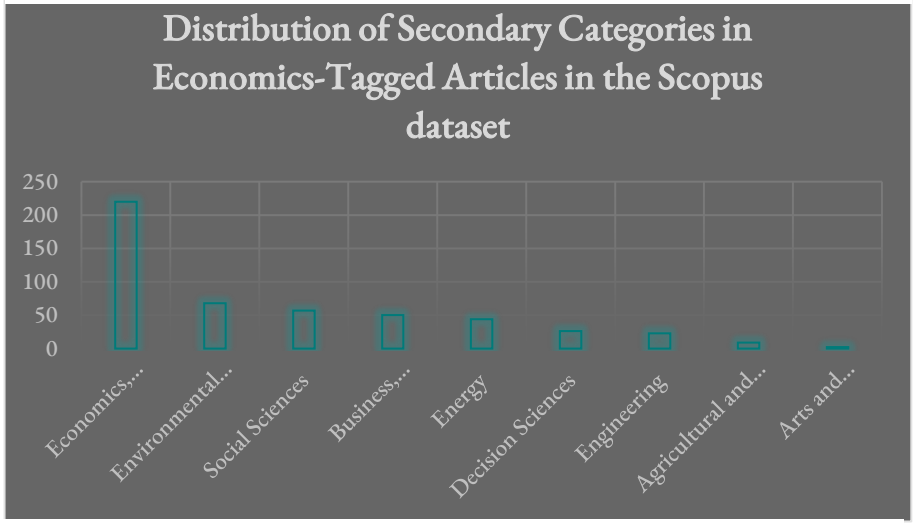
Panel B



Panel C



Panel D



Source: generated by the author using data retrieved from Scopus and Web of Science (WoS)

Table 13: Overall Descriptive Statistics for Keywords in Co-occurrence Analysis (N=110)

Links		*Total link strength*		*Occurrences*		*Avg. pub. year*		*Avg. citations*		*Avg. norm. citations*	
Mean	41,04	Mean	86,45	Mean	13,55	Mean	2020,75	Mean	31,82	Mean	1,24
Median	36,50	Median	56,00	Median	9,00	Median	2020,89	Median	30,20	Median	1,13
Standard Deviation	18,52	Standard Deviation	81,93	Standard Deviation	12,87	Standard Deviation	1,50	Standard Deviation	16,19	Standard Deviation	0,53
Range	81,00	Range	499,00	Range	76,00	Range	7,27	Range	87,60	Range	2,94
Minimum	16,00	Minimum	17,00	Minimum	5,00	Minimum	2016,33	Minimum	2,40	Minimum	0,28
Maximum	97,00	Maximum	516,00	Maximum	81,00	Maximum	2023,60	Maximum	90,00	Maximum	3,22
Sum	4514,00	Sum	9510,00	Sum	1491,00	Sum	222282,02	Sum	3499,72	Sum	136,09
Count	110,00	Count	110,00	Count	110,00	Count	110,00	Count	110,00	Count	110,00

Source: generated by the author using data retrieved from Scopus and Web of Science (WoS)

Figure 6 Thesarus (synonym) file used for the keyword co-occurrence analysis in Vosviewer

carbon dioxide emissions CO2 emissions

carbon dioxide emission CO2 emissions

carbon-dioxide emissions CO2 emissions

co2 emission CO2 emissions

co2 emissions CO2 emissions

co₂ emissions CO2 emissions

dioxide emissions CO2 emissions

carbon emission CO2 emissions

carbon emissions CO2 emissions

carbon dioxide co2

carbon footprints carbon footprint

carbon price carbon pricing

bio-energy bioenergy

biofuel biofuels

carbon taxes carbon tax

corporate social-responsibility corporate social responsibility

decision-making decision making

decisions decision making

decision support systems decision making

economic-growth economic growth

energy-consumption energy consumption

environmental impacts environmental impact

environmental regulations environmental regulation

environmental-regulation environmental regulation

foreign direct-investment foreign direct investment

direct-investment foreign direct investment

global supply chains global supply chain

greenhouse gas (ghg) emissions GHG emissions

greenhouse-gas emissions GHG emissions

gas emissions GHG emissions

gas emission GHG emissions

greenhouse gas emissions GHG emissions

greenhouse gases GHG

greenhouse-gas GHG

greenhouse gas GHG

input output analysis input-output analysis

input-output-analysis input-output analysis

input-output input-output analysis

input-output database input-output analysis

input-output model input-output analysis

input-output table input-output analysis

input–output models input-output analysis

input-output linkages input-output analysis

output analysis input-output analysis

c67 input-output analysis

international-trade international trade

life-cycle assessment life cycle assessment

life cycle analysis life cycle assessment

lca life cycle assessment

life cycle life cycle assessment

life cycle assessment (lca) life cycle assessment

materials flow analysis material flow analysis

dynamic material flow analysis material flow analysis

multiobjective optimization multi-objective optimization

panel-data panel

panel data panel

renewable energy resource renewable energy resources

renewable energy source renewable energy resources

supply chains supply chain

energy transitions energy transition

impacts impact

mineral resource mineral resources

minerals mineral resources

policies policy

energy use energy consumption

climate-change climate change

global warming climate change

global value chain GVC

global value chains GVC

investments investment

stochastic systems stochastic models

stochastic model stochastic models

multi-regional input-output analysis input-output analysis

financial finance

driving forces drivers

alternative energy renewable energy

aggregate embodied energy embodied energy

exports export

footprints footprint

ecological footprint footprint

policies policy

energy transitions	energy transition
environmental impacts	environmental impact
automotive industry	automobile industry
cap-and-trade	cap and trade
case studies	case study
construction	construction industry
construction sectors	construction industry
costs	cost
critical minerals	critical raw materials
decarbonization	decarbonisation
electric vehicle	electric vehicles
embodied carbons	embodied carbon
embodied co2 emissions	embodied emissions
emissions embodied in trade	embodied emissions
eu-ets	eu ets
eu	Europe
European union	Europe
FDI	foreign direct investment
fuels	fuel
global value	GVC
global value chain (gvc)	GVC
gravity	gravity model
land-use	land use
low-carbon transitions	low-carbon transition
manufacture	manufacturing
market	markets
optimisations	optimisation
regulations	regulation
renewable	renewable energy
sector	sectors
structural path-analysis	structural path analysis
transport	transportation
clean energy	renewable energy
green energy	renewable energy
environmental technology	green technology
carbon emission reduction	emission reduction
structural decomposition analysis	decomposition analysis
monte carlo method	stochastic models
solid waste management	waste management
growth	economic growth
climate	climate change
leakage	carbon leakage
environmental sustainability	sustainability
green supply chain management	green supply chains
green supply chain	green supply chains
zero carbons	decarbonisation
zero-carbons	decarbonisation
zero-carbon	decarbonisation
zero-carbons	decarbonisation
carbon neutrality	decarbonisation
world-trade	WTO
world trade organization	WTO
trade organization	WTO
united-states	United States
trade in value added (tiva)	GVC
through international trade	international trade
tax policies	tax policy
taxation	tax policy
tax	taxes
tax expenditures	tax policy
tax incentives	tax policy
supply chain resiliences	supply chain resilience
supply chain managements (scm)	supply chain management
structural timbers	forestry
social-economics	social-economic
socio-economic consequences	social-economic
socioeconomics	social-economic
semiconductor device manufacture	semiconductor industry
second generation	biofuels
scope 2 and scope 3 emissions	carbon accounting
scope 1	carbon accounting
russian federation	Russia
resource curse paradox	resource curse
research-and-development	R&D
renewable energies	renewable energy
renewable energy auction	renewable energy
renewable energy sources	renewable energy
renewable sources of energy consumption	renewable energy
reduction of emissions	emission reduction
production-based accounting (pba)	carbon accounting
off-shoring	offshoring
natural resource	natural resources
multi-region inputoutput	input-output analysis
multi-objective linear programming	multi-objective optimization

multi-objective optimization models	multi-objective optimization
inputoutput	input-output analysis
input–output models	input-output analysis
international-trade	international trade
lca	life cycle assessment
life cycle	life cycle assessment
life cycle assessment (lca)	life cycle assessment
globalization	globalisation
global value chain participation	GVC
green supply chain designs	green supply chains
forest property taxation and valuation	forestry
exiobase	input-output analysis
energy-transition	energy transition
environmental and social effects of green transformation	green transition
environmental life cycle analysis	life cycle assessment
environmental tax-reform	environmental tax
environmental-impact	environmental impact
environmental-impacts	environmental impact
energy productions	energy production
energy sources	energy resources
energy resource	energy resources
energy-requirements	energy demand
emissions trading	carbon markets
embodied co2 emissions	embodied emissions
embodied emission	embodied emissions
ecological impacts	environmental impact
direct-investment evidence	foreign direct investment
developed country	developed countries
developing country	developing countries
developing world	developing countries
corporate sustainability	corporate social responsibility
csr	corporate social responsibility
closed-loop	circular economy
closed-loop networks	circular economy
closed-loop supply chain	circular economy
circular policies	circular policy
circular biobased economy	circular economy
cge modeling	computable general equilibrium
cge modelling	computable general equilibrium
carbon peaks	CO2 emissions
co₂ emissions embodied in exports	embodied emissions
bio-methanol	biofuels
biofuel production	biofuels
biogas	biofuels
bioenergy conversion	bioenergy
backward-forward linkages	GVC
analysis of variance	ANOVA
analysis of variance (anova)	ANOVA
agricultural wastes	agriculture
agricultural wastes	agriculture
agricultural worker	agriculture
agricultural workers	agriculture
aggregate embodied carbon emission	embodied emissions
3-d printing	additive manufacturing
3d printing	additive manufacturing
wood	forestry
optimization	optimisation
trade	international trade

Table 14 Top 10 Keywords in the keyword co-occurrence analysis by Various Metrics

Panel A Links			Panel B TLS			Panel C Occurrences			Panel D Avg. pub. year			Panel E Avg. citations			Panel G Avg. norm. citations		
Keyword	cluster	Links	Keyword	cluster	Total link strength>	Keyword	cluster	Occurrences	Keyword	cluster	Avg. pub. year	Keyword	cluster	Avg. citations	Keyword	cluster	Avg. norm. citations>
co2 emissions	3	97	co2 emissions	3	516	co2 emissions	3	81	governance	2	2023,6	multi-objective optimization	1	90,0	profitability	1	3,217
china	4	92	international trade	3	398	international trade	3	65	material flow analysis	4	2023,17	green supply chains	1	75,6	circular economy	1	2,7278
international trade	3	89	supply chain	1	316	climate change	1	53	foreign direct investment	3	2022,94	cap and trade	2	70,6	recycling	4	2,5966
supply chain	1	88	climate change	1	313	supply chain	1	52	performance	2	2022,9	industry	2	68,9	manufacturing	4	2,4995
climate change	1	88	china	4	299	input-output analysis	3	47	gvc	3	2022,86	environmental protection	1	64,6	corporate social responsibility	2	2,3606
carbon footprint	3	81	input-output analysis	3	275	china	4	43	panel	3	2022,8	tax policy	2	63,3	industry	2	2,1457
carbon	1	80	carbon	1	234	gvc	3	36	energy intensity	2	2022,8	financial performance	2	61,5	sustainable development	1	2,0558
sustainable development	1	74	sustainable development	1	204	economic growth	3	35	profitability	1	2022,8	agriculture	1	60,8	ghg	1	2,019
input-output analysis	3	74	gvc	3	202	carbon	1	33	low-carbon transition	4	2022,8	co2	4	57,1	outsourcing	1	1,9142
ghg	1	73	economic growth	3	199	sustainable development	1	30	uncertainty	1	2022,71	ghg	1	54,9	sustainability	1	1,8985

Source: generated by the author using data retrieved from Scopus and Web of Science (WoS)

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