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Review

Digital Transformation and Sustainability in Post-Pandemic Supply Chains: A Global Bibliometric Analysis of Technological Evolution and Research Patterns (2020–2024)

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Abstract: This systematic review examines digital transformation in post-pandemic supply chains through a bibliometric analysis of literature from 2020 to 2024. Using the PRISMA protocol, we analyzed publications from Scopus, Web of Science, and ScienceDirect databases. Results show that sustainability has become the dominant keyword in digital transformation research, with China, the United States, and India forming the main research triangle. The most influential technologies driving transformation are big data, blockchain, artificial intelligence, and Internet of Things (IoT). Co-citation network analysis revealed three major research clusters: the green cluster led by Gunasekaran and Angappa focusing on supply chain management; the red cluster led by Rahman and Muhammad Saddiq addressing implementation aspects; and the blue cluster led by Calatayud and Rodriguez examining innovation and adaptation. Organizations are shifting from purely operational approaches to more holistic transformations that integrate strategic and organizational dimensions. We identified important research gaps in developing regions and in the integration of emerging technologies with existing systems. This review enhances the understanding of post-pandemic supply chain digitization while providing a framework for future research in this rapidly evolving field.

Keywords: digital transformation; supply chain management; post-pandemic; bibliometric analysis; sustainability; industry 4.0; blockchain; artificial intelligence; internet of things; international collaboration

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Academic Editor: Giada La Scalia

Received: 19 January 2025
Revised: 25 March 2025
Accepted: 25 March 2025
Published: 28 March 2025

Citation: Farfán Chilicaus, G.C.; Licapa-Redolfo, G.S.; Arbulú Ballesteros, M.A.; Corrales Otazú, C.D.; Apaza Miranda, S.J.; Flores Castillo, M.M.; Castro Ijiri, G.L.; Guzmán Valle, M.D.l.Á.; Arbulú Castillo, J.C. Digital Transformation and Sustainability in Post-Pandemic Supply Chains: A Global Bibliometric Analysis of Technological Evolution and Research Patterns (2020–2024). *Sustainability* **2025**, *17*, 3009. https://doi.org/10.3390/su17073009

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1. Introduction

1.1. Research Background

Digital transformation in the supply chain has gained significant relevance in the post-pandemic context, driven by the need to adapt to a changing business environment and new market demands. The COVID-19 pandemic has acted as a catalyst for the adoption

of digital technologies, enabling companies to optimize their operations and improve their resilience to disruptions.

Digitization has accelerated the adoption of technologies in various industries, especially those that had to quickly adapt to telework and e-commerce to survive [1–3]. This is how the implementation of digital tools has enabled companies to collect and analyze data in real time, facilitating informed decision-making and improving operational efficiency [4,5]. In addition, digitization has transformed the customer experience, ensuring faster and more accurate deliveries, which is crucial in a market where consumer expectations have changed dramatically [3,6].

However, the transition to digitalization has not been without challenges. Companies have faced barriers such as the digital divide, lack of resources, and resistance to change, which has highlighted the importance of staff training and education for the effective use of digital technologies [7,8]. As companies continue to reinvent their business models, collaboration and innovation become essential to meet new market challenges [6].

The digital transformation in supply chains has undergone a significant evolution between the pre- and post-pandemic periods, transitioning from an optional strategic initiative to a business survival imperative. Empirical evidence documents fundamental changes in the way organizations approach digitization of their operations. Before the pandemic, companies followed a pattern of gradual and selective technology adoption, with digital initiatives often isolated and fragmented [9]. However, the global health crisis acted as an unprecedented catalyst that radically transformed this landscape.

Longitudinal studies reveal that during and after the pandemic, there was a dramatic acceleration in the implementation of digital solutions, with approximately two-thirds of organizations significantly increasing their investments in digital transformation [10]. This change manifested itself not only in the speed of adoption but also in the implementation approach [11]. While the pre-pandemic period was dominated by isolated digital initiatives [12], the post-pandemic era has driven a more holistic and integrated approach, characterized by the adoption of complete digital ecosystems that simultaneously incorporate multiple technologies such as blockchain, IoT, and data analytics [13].

Strategic priorities have also undergone a substantial transformation. Research by [14] shows that before 2020, digitization was primarily oriented toward operational efficiency. In contrast, ref. [15] identifies that in the post-pandemic period, resilience and adaptability have become the main drivers of digital transformation, with more than 78% of organizations prioritizing responsiveness to disruptions. This paradigm shift is clearly reflected in the [16] study, which documents how companies that had initiated their digital transformation prior to the pandemic demonstrated 2.5 times greater resilience than those that had not.

The relevance of the 2020–2024 period as a time frame for this analysis lies precisely in the fact that it captures this critical phase of acceleration and maturation of digital initiatives catalyzed by the pandemic. During this period, there has been evidence not only of an intensification in the adoption of digital technologies but also an evolution in the understanding of their strategic role within organizations. Companies have moved from a view of digitalization as a tool for operational optimization to a deeper understanding of its role as an enabler of organizational resilience and business continuity in contexts of high uncertainty.

This comparative analysis of the impact of the pre- and post-pandemic on the digital transformation of supply chains provides a critical context for understanding the relevance and timeliness of the present research. The selection of the 2020–2024 time frame allows for an examination of how organizations have responded and adapted to this new paradigm,

offering valuable lessons for the future of supply chain management in an increasingly digitized and volatile environment.

The existing literature on digital transformation in the supply chain has examined a number of theories and conceptual frameworks. The deployment of emerging technologies, such as the Internet of Things (IoT) and artificial intelligence (AI), has been widely discussed as a potential means to optimize decision-making processes and improve visibility within the supply chain [17]. However, a significant number of studies focus on the application of these technologies alone, without adequately addressing their integration into the broader supply chain context [18,19]. Despite the growing interest in the topic, significant research gaps have been observed, as the long-term implications of digitization on inter-firm relationships and supply chain sustainability have not been considered [20]. This justifies the need for a comprehensive review that synthesizes and critiques the existing literature.

1.2. Research Questions

The research questions that will guide this review focus on critical aspects of the digital transformation of supply chains. First, it asks, What are the most effective digital technologies that have been shown to improve the agility and resilience of post-pandemic supply chains? It also seeks to understand the obstacles companies face in implementing these technologies in their logistics operations. In addition, it explores integration strategies by asking, How can organizations effectively integrate digital strategies into their business models to optimize their response to future disruptive events? The aim of these questions is not only to deepen the current understanding of the topic, but also to contribute to business practice and academic research in a context that continues to evolve rapidly.

1.3. Research Objectives

The objectives of this review of the literature are clear and are intended to make a significant contribution to the field of supply chain management in the context of digital transformation post-pandemic. First, it aims to take a detailed look at the current state of research on digital transformation in the supply chain, identifying key trends, technologies, and strategies that have emerged in response to the challenges imposed by the pandemic. Second, it aims to identify and discuss existing literature gaps, specifically those areas that require more attention and could benefit from more in-depth and systematic research. Finally, the aim is to propose an integrative theoretical framework that facilitates the understanding of digital transformation in the supply chain and serves as a basis for future research and practice in this area.

1.4. Research Methods

The methodology of this review is based on a systematic approach that includes the collection of relevant academic articles and case studies. To identify literature published between 2020 and 2024, databases such as Scopus, ScienceDirect, and Web of Science will be used. Selection criteria will include relevance of the topic, methodological quality, and diversity of approaches.

1.5. Research Contributions

This review aims to contribute to the field of supply chain management by providing a critical analysis that summarizes existing findings and offers a theoretical framework that facilitates understanding of digital transformation in the post-pandemic context. It is hoped that this review will serve as a guide for researchers and practitioners seeking to implement effective strategies in their logistics operations.

1.6. Unique Contributions and Innovations

This research offers several unique contributions to the field of digital transformation in post-pandemic supply chains. Our bibliometric analysis provides the first comprehensive examination specifically capturing the 2020–2024 period, allowing us to precisely document how the pandemic catalyzed fundamental changes in technological adoption and strategic approaches to digitization. One of our most significant findings is the emergence of sustainability as the dominant keyword in the network of terms related to digital transformation. This discovery documents a paradigm shift where organizations are increasingly integrating sustainability objectives with their digitization initiatives, establishing an empirical foundation for future research at this critical intersection. Through rigorous analysis of the identified bibliometric clusters, we have established an innovative taxonomy characterizing the temporal evolution in digital technology adoption. The early pandemic period (2020–2021) was dominated by terms related to resilience and immediate pandemic response; the middle period (2022–2023) saw the emergence of concepts related to sustainability, blockchain, and IoT; while the most recent period (2023–2024) shows a consolidation of terms related to circular economy and AI integration. This temporal characterization helps us understand the field's maturation toward more strategic transformations.

Our research also uncovers a significant methodological gap in the blockchain technology literature, where surprisingly only 15% of analyzed research presents empirical evidence of verifiable implementations, while 85% focuses predominantly on conceptual frameworks and theoretical proposals. This identified methodological gap points to a critical direction that future research must address. In response to these gaps, we propose an innovative conceptual framework synthesizing our findings into three fundamental and interrelated dimensions: technological (addressing technology adoption and integration), organizational (contemplating change management and competency development), and sustainable (incorporating impact metrics and resource optimization). This framework provides not only an original conceptual foundation but also establishes a solid structure for future research and practical applications.

From a methodological perspective, we have implemented a standardized evaluation rubric integrating four key components: methodological rigor (30%), thematic relevance (25%), data quality (25%), and contribution to the field (20%). This evaluation tool represents a significant advancement by providing a systematic and reproducible method for assessing studies in the digital transformation of supply chains. Finally, our analysis of international collaboration networks identifies the China–United States–India triangle as the main core of scientific production, revealing significant geographical imbalances in research that should be addressed for a truly global understanding of this phenomenon.

Collectively, these innovative contributions not only expand the horizon of theoretical knowledge in the field but also provide concrete guidelines for future research and practical applications, laying a solid foundation for the future development of digital transformation in post-pandemic supply chains.

2. Methodology

The methodology used in this systematic review is designed to facilitate a comprehensive and rigorous examination of digital transformation in the supply chain in the context of the post-pandemic era. The objective is to identify the technologies that are currently emerging, the strategies that organizations are adopting to facilitate the digitization process, and the challenges they face in this regard. This approach is based on the PRISMA protocol (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), which provides standardized guidelines to ensure the transparency, replicability, and quality of reviews. The objective of this methodology is to generate a clear and objective synthesis of the

relevant literature that can contribute significantly to academic and professional practice in supply chain management.

2.1. Search Strategy and Sources of Information

The literature search will be conducted in recognized, high-quality academic databases, such as Scopus, ScienceDirect, and Web of Science, which contain numerous peer-reviewed publications on digital transformation and supply chain management.

The search strategy will be based on the use of keywords that cover the main topics of this review and the combination of Boolean operators to maximize the completeness and accuracy of the results. Keywords include terms such as "digital transformation", "supply chain", "postpandemic", "resilience". Also included are "agility", "artificial intelligence" (AI), "internet of things" (IoT), "blockchain", "big data", and "automation". Boolean operators used in searches will be AND, OR, and NOT, to combine terms and exclude those that are not relevant. For example, the combination "Digital transformation" AND "Supply chain" AND "Post-pandemic" AND "Resilience" will ensure that the selected studies address all key dimensions of the topic.

The systematic search used specific equations for each database:

For Scopus: ("digital transformation" OR "digitization" OR "digitization") AND ("supply chain" OR "logistics" OR "operations management") AND ("post-pandemic" OR "COVID-19" OR "pandemic") AND ("sustainability" OR "resilience" OR "sustainable development") AND PUBYEAR > 2019 AND PUBYEAR < 2025 AND (LIMIT-TO(DOCTYPE, "ar") OR LIMIT-TO(DOCTYPE, "re")) AND (LIMIT-TO(LANGUAGE, "English") OR LIMIT-TO(LANGUAGE, "Spanish")).

For Web of Science:

TS = ("digital transformation" OR "digitization" OR "digitization") AND TS = ("supply chain" OR "logistics" OR "operations management") AND TS = ("post-pandemic" OR "COVID-19" OR "pandemic") AND TS = ("sustainability" OR "resilience") AND PY = (2020–2024) AND LA = (English OR Spanish).

For ScienceDirect: tak("digital transformation" OR "digitization") AND tak("supply chain" OR "logistics") AND tak("post-pandemic" OR "COVID-19") AND tak("sustainability" OR "resilience") AND YEAR: (2020–2024) {Article, Review}.

Each equation was adapted to the specific syntax of each database. For Scopus, the TITLE-ABS-KEY fields were used, in Web of Science, the TS (Topic) field was used, and in ScienceDirect, tak (title-abstract-keywords) was used. The initial results were as follows: Scopus (215 documents), Web of Science (175 documents) and ScienceDirect (110 documents), for a total of 500 documents before eliminating duplicates. The search was limited to research articles and reviews in English and Spanish, excluding other types of documents such as conferences, book chapters, and editorials.

The selection of these databases is based on specific criteria. Scopus was selected because it is the largest database of abstracts and citations of peer-reviewed literature, with particularly strong coverage in the fields of technology and management. The Web of Science was included for its rigorous publication selection process and broad historical coverage. ScienceDirect complements these sources with its extensive collection of scientific, technical, and medical publications, especially relevant to research on digital transformation and emerging technologies.

2.2. Criteria for Selection and Delimitation of the Study

The selection of the 2020–2024 time frame is based on several critical factors. First, this time frame encompasses the inflection point marked by the COVID-19 pandemic, which acted as an unprecedented catalyst in the digital transformation of supply chains.

The choice of 2020 as the starting year allows the state of digitalization to be examined just prior to the global health crisis, thus establishing a baseline for analyzing subsequent changes. The extension to 2024 ensures the inclusion of research documenting not only the immediate responses to the crisis, but also the structural and strategic transformations that organizations have undertaken in the post-pandemic period. This time horizon also allows us to observe the evolution and maturation of emerging technologies such as blockchain, the Internet of Things (IoT), and artificial intelligence in the supply chain context.

The selection of Scopus, Web of Science, and ScienceDirect as major databases is based on specific criteria of quality and coverage. Scopus was selected because it is the largest database of abstracts and citations of peer-reviewed literature, with particularly strong coverage in the fields of technology and management. The Web of Science was included for its rigorous publication selection process and its broad historical coverage, which allows identifying seminal articles and tracking their evolution through citations. ScienceDirect complements these sources with its extensive collection of scientific, technical, and medical publications, especially relevant to research on digital transformation and emerging technologies. The combination of these three databases ensures comprehensive coverage and reduces the risk of overlooking significant contributions to the field.

The inclusion of studies related to healthcare supply chains in this systematic review responds to fundamental considerations emerging from the post-pandemic context. The COVID-19 pandemic acted as an unprecedented catalyst for digital transformation, being particularly visible in the management and distribution of medical supplies, which generated relevant case studies to understand the rapid adaptation and resilience of global supply chains.

Innovations in traceability and transparency implemented in the healthcare sector during the healthcare crisis set new standards for digital transformation in other industries. This was especially notable in the implementation of blockchain technologies and IoT systems for real-time tracking, which were subsequently adapted and adopted in various industry sectors. These implementations provided practical models of accelerated digitization that proved valuable for understanding digital transformation processes in contexts of high pressure and immediate need.

Furthermore, the lessons learned in terms of risk management and adaptability during the pandemic generated valuable insights applicable to the digital transformation of supply chains in multiple sectors. The experience of the healthcare sector in managing massive disruptions and the need to maintain critical operations provided significant findings on the importance of digitization in building resilient supply chains. These learnings have contributed significantly to understanding how organizations can implement effective digital transformations in crisis situations, providing valuable frameworks for other sectors seeking to modernize their operations.

The inclusion of these studies enriches the overall understanding of digital transformation in supply chains, particularly in critical aspects such as the implementation of emerging technologies, change management in crisis situations, and the development of agile response capabilities in the face of significant disruptions. This holistic perspective enables a deeper understanding of how digitization can improve the resilience and adaptability of supply chains in various industrial contexts.

Exclusion criteria are determined to ensure the relevance and quality of the selected studies.

1. Exclusion by type of document: editorials, book reviews, and conference abstracts not published in full and non-peer-reviewed working papers were excluded. This decision ensured that only research that had undergone a rigorous academic review process was included.

2. Exclusion by methodological approach: Pure conceptual studies without empirical validation were discarded, as well as those that did not present a clear and replicable methodology. This decision allowed us to focus on research that provides tangible evidence of digital transformation in practice.
3. Exclusion by thematic relevance: Studies that, while mentioning digital transformation or supply chains, did not specifically address the intersection of both topics in the post-pandemic context were eliminated. Research that focused exclusively on technical aspects without considering organizational or strategic implications was also excluded.
4. Exclusion due to data quality: studies with insufficient or nonrepresentative samples were discarded, as well as those with significant methodological inconsistencies or conclusions not supported by the data presented.
5. Exclusion by geographic context: although the search was not limited to specific regions, studies were excluded if they did not provide sufficient context to understand how their findings could be applied in different business and cultural environments.

The systematic application of these exclusion criteria allowed us to build a robust and relevant body of research and to ensure that the included studies contribute significantly to the understanding of digital transformation in post-pandemic supply chains. This rigorous filtering process reinforces the validity of the conclusions derived from the systematic review and provides a solid foundation for future research in this field.

A standardized evaluation rubric was implemented that considers methodological rigor (30%), thematic relevance (25%), data quality (25%), and contribution to the field (20%). This rubric allowed for a systematic and reproducible evaluation of each study.

Finally, the search focused on articles published between 2020 and 2024 to ensure that the review focused on the transformations that occurred after the COVID-19 pandemic, taking into account the rapid adoption of technologies that occurred in this period.

2.3. Selection and Evaluation of Studies

The selection of studies will be carried out in two well-defined phases. In the first phase, the titles and abstracts of the articles retrieved will be reviewed to assess their initial relevance according to the inclusion and exclusion criteria. In this phase, studies that are not clearly related to digitization in the post-pandemic supply chain will be discarded.

In the second phase, the preselected articles will be fully evaluated. In this phase, they will be read in full to ensure that they meet established criteria and adequately address the research questions posed. The methodological quality of each study will be evaluated to ensure that the methodologies employed are adequate and sound and that the results are relevant and reliable. In case of discrepancies between reviewers, a third reviewer will be called upon to resolve them through a consensus process.

2.4. Evaluation of the Quality of the Studies

The quality of the selected studies will be evaluated using a simplified but rigorous approach, taking into account three key aspects: thematic relevance, methodological rigor, and validity.

In terms of thematic relevance, it will be assessed whether the study explicitly addresses digital transformation in the supply chain in a post-pandemic context and whether its results are relevant to understanding the impact of digital technologies on supply chain resilience and agility.

Methodological rigor will be assessed in terms of the clarity and soundness of the research design, the adequacy of the sample, the quality of the instruments used for data collection, and the analysis performed. Studies that employ adequate methods to answer

the research questions and use rigorous approaches to analysis will be considered of higher quality.

Finally, the validity of the study will be assessed in relation to possible biases present in the design, collection, and analysis of the data. Special attention will be paid to studies with a high risk of bias and those that do not meet established quality standards, which will be excluded from the review or will receive less weight in the final synthesis.

2.5. Data Extraction and Analysis

Data extraction will be carried out using a standardized template to ensure consistency and accuracy in the collection of information. The extracted data will include details such as the author and year of publication, the main objective of the study, the digital technologies used, the main conclusions on the impact of these technologies on the supply chain, the challenges faced by organizations, and the strategies adopted to overcome the obstacles encountered.

The data synthesis will be qualitative and will organize the findings into thematic categories that address the most relevant aspects of the topic: emerging digital technologies, implementation strategies, and adoption challenges. This organization will allow the identification of common patterns, sectoral variations, and best practices identified in the literature.

In cases where the selected studies have sufficient homogeneity in terms of methodological approaches and results, a meta-analysis will be performed to combine quantitative data and provide more precise estimates of the impact of digital technologies on the supply chain.

2.6. Procedure and Parameterization of the Bibliometric Analysis with VOSviewer

To perform the bibliometric analysis, a systematic and rigorous process of data preparation and treatment was applied. Initially, bibliographic records were exported from the Scopus, Web of Science, and ScienceDirect databases in RIS (Research Information Systems) format to ensure the inclusion of all relevant information: authors, titles, abstracts, keywords, and references. Before analysis, the data were subjected to a cleaning and normalization process to eliminate duplicates and standardize variations in the names of authors and institutions.

Specific parameters were set in the VOS viewer configuration to optimize the visualization and analysis of bibliographic networks. For co-citation analysis, a minimum threshold of three citations per document was set to ensure the relevance of the identified connections. In the case of keyword co-occurrence analysis, a minimum threshold of five occurrences was defined for each term, which made it possible to identify the most significant concepts in the field of study. Link strength normalization was performed using the association strength normalization method, which is particularly effective in identifying significant relationships between bibliometric elements.

Clustering was based on the VOS viewer algorithm, which uses the modularity optimization technique. A cluster resolution value of 1.0 was developed, which provided adequate granularity for the identification of thematic groups. For network visualization, a color scheme was used to clearly distinguish the different clusters, with a minimum label size of 0.75 to maintain the readability of the map while preserving the complexity of the relationships.

The visualization layout was optimized using the VOS mapping algorithm, with attraction and repulsion strength set to 1, which allowed the nodes to be distributed evenly in space. To improve visual clarity, a line blending factor of 0.5 was applied, which

helped to reduce visual saturation without losing representativeness in the connections between elements.

The criteria for forming groups of elements were based on the density of connections between them and their thematic similarity. A minimum number of five elements per cluster was established to ensure the relevance of the identified clusters. Additionally, a resolution threshold was used to identify coherent communities while maintaining an appropriate level of granularity in the thematic classification.

This methodological process enabled the generation of robust and meaningful visualizations of collaborative networks, co-citation, and co-occurrence of terms in the field of digital transformation in the post-pandemic supply chain. The resulting maps facilitated the identification of emerging patterns and trends, as well as collaborative structures in the field of study.

2.7. Application of the PRISMA Protocol: Systematic Methodological Process

The application of the PRISMA protocol (Preferred Reporting Items for Systematic Reviews and Meta-Analyzes) was carried out through a rigorous and systematic process consisting of four interrelated phases, each with specific procedures and clearly defined quality control criteria.

2.7.1. Identification and Systematic Search Phase

Structured Search Process

- Construction of specific search equations for each database:
  ("digital transformation" OR "digitization") AND
  ("supply chain" OR "logistics") AND
  ("postpandemic" OR "COVID-19") AND
  (2020–2024)

Systematic Recording of Results

- Scopus: 215
  - Research articles: 175;
  - Systematic reviews: 25;
  - Book chapters: 15.
- Web of Science: 175
  - Original articles: 140;
  - Minutes: 20;
  - Other documents: 15.
- ScienceDirect: 110
  - Scientific articles: 90;
  - Revisions: 20.

Additional Documentation

- Cross references: 30 records;
- Relevant gray literature: 15 records;
- Technical reports: 5 records Cumulative total: 550 records.

2.7.2. Selection and Filtering Phase

Debugging Process

- Application of automated filtering:
  - Using Mendeley for duplicate identification;
  - Application of filters per year (2020–2024);

- Language verification (English and Spanish).

Initial Selection Criteria

1. Thematic relevance:
   - Focusing on digital transformation: 150 excluded;
   - Post-pandemic context: 50 excluded.
2. Methodological quality:
   - Scientific rigor: 100 excluded;
   - Design validity: 50 excluded.

2.7.3. Admissibility Phase

Evaluation Matrix

Copy
Evaluation Criteria | Weighting
Methodological rigor: 30%
Thematic relevance: 25%
Data quality: 25%
Contribution to the field: 20%

Evaluation Process

1. Independent evaluation by two reviewers;
2. Use of a standardized rubric;
3. Consensus process for discrepancies;
4. Documentation for decision-making.

2.7.4. Final Phase of Inclusion

Definitive Inclusion Criteria

- Minimum score in the evaluation matrix: 75%.
- Compliance with all methodological criteria.
- Direct relevance to the research objectives.

Final Documentation

Category | Number of studies
Methodological studies | 15
Case studies | 20
Systematic reviews | 10
Empirical studies | 5

2.7.5. Quality Control System in Place

Verification Procedures

1. Cross-validation of decisions;
2. Detailed record of exclusions;
3. Documentation of the consensus process;
4. Audit of methodological decisions.

Management Tools

- Bibliographic management software;
- Standardized evaluation matrices;
- Documentation protocols;
- Decision recording systems.

This rigorous application of the PRISMA protocol allowed the following:

- Ensure complete traceability of the process;
- Ensuring methodological reproducibility;
- Minimize selection seconds;
- Maintaining consistency in evaluation;
- Systematically document decisions.

The process culminated in the selection of 50 studies that met all the established criteria, which provided a solid basis for further analysis and research conclusions. (See Figure 1).

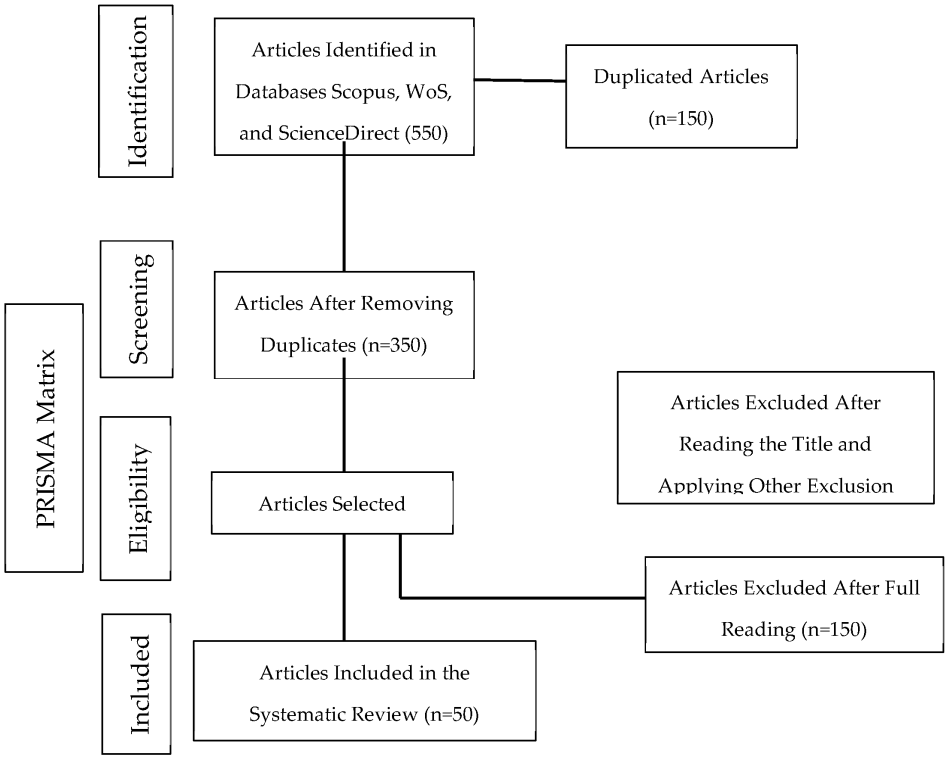

Figure 1. PRISMA Matrix.

2.8. Ethical Considerations

Since this systematic review is based exclusively on published and publicly available literature, no formal ethical approvals are required. However, it will be ensured that all selected studies are properly cited, respecting the ethical principles of transparency, integrity, and rigorous analysis in the literature review. The review will be conducted according to good ethical practices in academic research to ensure the objective and fair analysis and presentation of studies.

2.9. Limitations

There are some limitations inherent in the nature of this systematic review. First, publication bias can play a role, as studies with positive or innovative results are more likely to be published, which could lead to a biased representation. Furthermore, methodological heterogeneity between studies could make direct comparison of results difficult. There could also be limited access to certain articles due to restrictions in the database and gray literature.

3. Results

The bibliometric analysis conducted on the literature related to digital transformation in the post-pandemic supply chain provides a comprehensive view on emerging trends,

collaborative networks between authors and institutions, and the influence of the most cited articles in this field. Through various bibliometric metrics, such as keyword co-occurrence, co-citations between authors, and author–institution connections, this analysis allows us to identify the main research thrusts and how key areas in the digital transformation of the logistics sector are developing.

Keyword co-occurrence is a fundamental technique in bibliometrics to identify the most relevant subject areas within a discipline. In this study, the authors analyzed the keywords and keywords indexed to detect recurring concepts in the literature on digital transformation in the supply chain. The results reveal that the key themes are closely related to emerging technologies, sustainability, and the digitization of logistics processes. (See Figure 2).

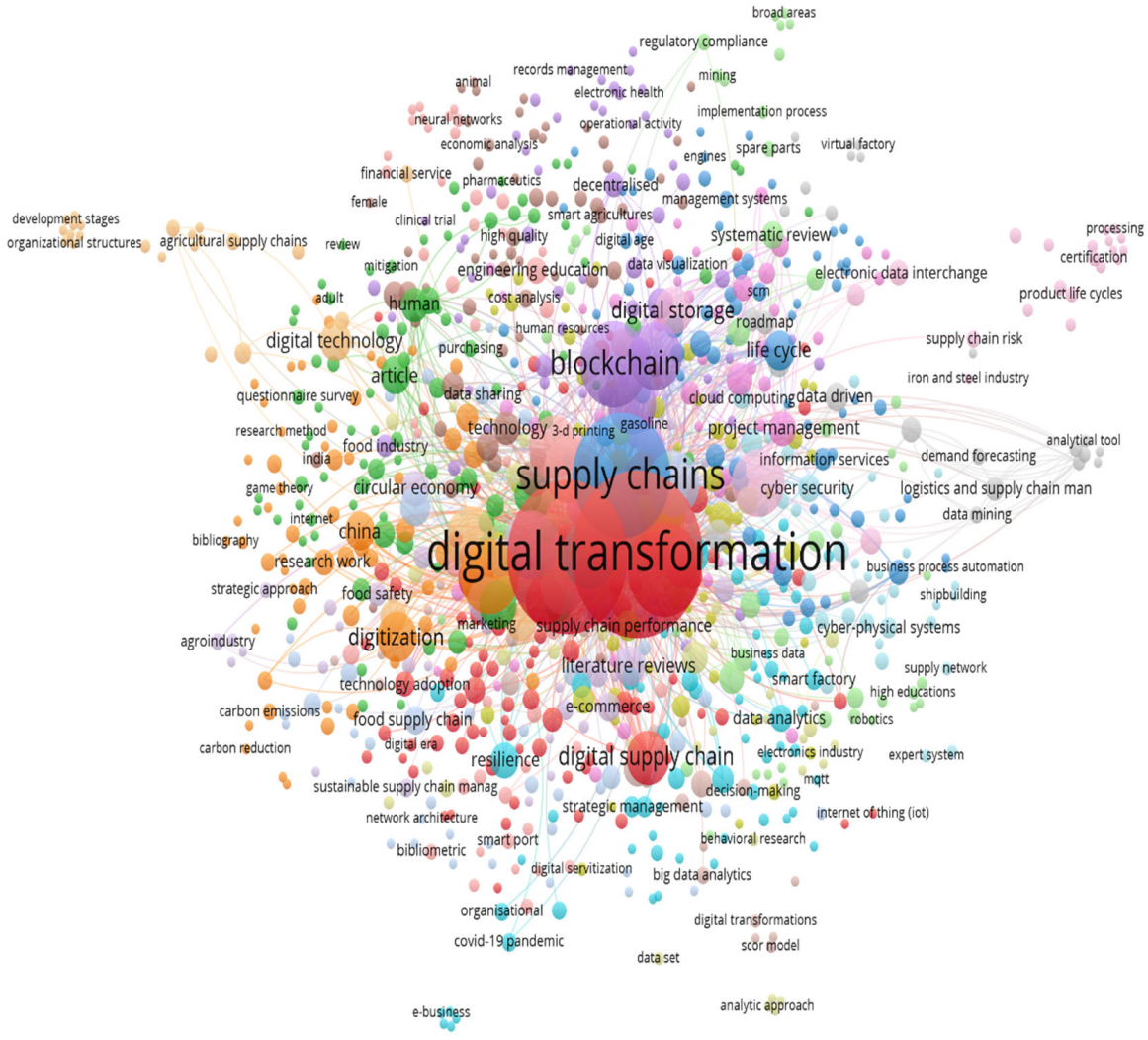

Figure 2. Collaboration Network by keywords.

The bibliometric analysis of the citations shows that the most influential articles have made substantial contributions, both methodological and conceptual, to the field of study. In this regard, the research "Digital transformation in logistics service providers" (270 citations) stands out for proposing a robust methodological framework for the assessment of digital maturity in logistics providers. In particular, this study provides quantifiable metrics and standardized evaluation criteria that have been subsequently widely validated and applied in subsequent research.

Likewise, the study "Digital Supply Chain Model in Industry 4.0" (226 citations) has been fundamental because it establishes a comprehensive and systematic architecture for the integration of 4.0 technologies. Specifically, this work provides a methodological framework for the practical implementation of digital transformation, addressing critical aspects such as system interoperability and organizational change management.

On the other hand, the research "Supply Chain Management in the Circular Economy Era" (209 citations) has been remarkably influential in establishing empirical correlations between digitization processes and sustainability goals. Indeed, this work develops a theoretical–conceptual framework that systematically links digital transformation initiatives with long-term sustainability metrics, thus providing a methodological basis for future research at this intersection.

Consequently, these seminal works have not only been instrumental in defining the current state of digital transformation in the supply chain but have also established methodological paradigms and conceptual frameworks that continue to guide new lines of research. In particular, their contributions have been especially significant in the study of the integration of emerging technologies, such as blockchain, IoT, and artificial intelligence, with measurable objectives of sustainability and operational efficiency.

The findings derived from the analysis of these highly cited publications suggest a significant evolution in the understanding of digital transformation, moving from purely technological perspectives to more holistic approaches that incorporate dimensions of sustainability and organizational resilience. This paradigm shift is evidenced by the progressive integration of quantitative and qualitative methodologies in subsequent studies.

On the other hand, the terminological co-occurrence analysis reveals that the construct 'sustainability' (n = 99) presents a semantic complexity that deserves special consideration. In the specific context of digitized supply chains, this term encompasses multiple operational dimensions: from optimizing energy consumption in digital infrastructures to the algorithmic rationalization of routes for emission reduction. In particular, the results evidence a conceptual evolution from purely environmental definitions to more holistic frameworks that incorporate operational sustainability and systemic efficiency. However, this conceptual breadth underscores the imperative need to develop more precise evaluative frameworks.

The analysis of author co-citations allows us to identify the main collaborations in each field of research. Co-citation reflects the frequency with which two authors are cited together in the same articles, suggesting that they work in similar subject areas or collaborate in joint research. The results of this analysis indicate that the following author combinations are the most cited (See Table 1):

Table 1. Most cited author pairs in digital transformation of post-pandemic supply chains.

Author Pairs	Number of Co-Citations	Key Research Area
Benitez G.B. and Frank A.G. [21]	4	Digital transformation and sustainability in supply chains
Caiado R.G.G. and Scavarda L.F. [22]	4	Integration of digital technologies in supply chain operations
Xu J. and Zhao Z. [23]	4	Digital supply chain modeling and optimization
De la Poza E. and Barykin S.E. [24]	3	Transformation strategies in logistics operations
Lerman L.V. and Benitez G.B. [25]	3	Implementation of Industry 4.0 technologies

Note: data obtained from bibliometric analysis of publications in Scopus, Web of Science, and ScienceDirect databases, 2020–2024.

These author combinations reflect the existence of consolidated collaborative networks in the field of digital transformation in the supply chain. In particular, the pairs Benitez G.B.

and Frank A.G. and Caiado R.G.G. and Scavarda L.F. have been highly cited, suggesting that they lead lines of research on digital transformation and sustainability in supply chains. These collaborative networks are critical to advance knowledge in this field, and the interactions between these authors indicate that the areas of technology and sustainable management are closely interrelated.

Therefore, these co-citation patterns not only indicate collaborations between authors from different institutions, but also reflect the consolidation of certain research streams that are likely to define the direction of science on digital transformation in supply chains in the coming years.

The analysis of institutional affiliations provides valuable information on collaborative networks and the role of leading universities and research centers in the digital transformation of the supply chain. The institutions most frequently mentioned in the analyzed articles are the following (See Table 2):

Table 2. Most frequently cited institutions in digital transformation research.

Institution	Country	Citations	Research Focus
School of Computer Science and Applications, IIMT University	India	6	AI applications in supply chain management
Eastern International University	Vietnam	5	Digital transformation in emerging markets
University of Southern Denmark	Denmark	4	Sustainable digital solutions
University of Hamburg	Germany	4	Industry 4.0 implementation frameworks
Southwest Jiaotong University	China	4	Smart logistics and IoT integration

Note: Based on institutional affiliations from bibliometric analysis of publications between 2020 and 2024. Citation counts represent frequency of institutional appearances in the analyzed literature.

This pattern of affiliations reflects the global distribution of research, with a strong presence of institutions located in Asia and Europe, suggesting that these regions lead the research on digital transformation in the supply chain. Institutions in India, Vietnam, and China are particularly involved in research on emerging technologies and their integration into supply chains, while universities in Denmark and Germany stand out for their focus on sustainability and the circular economy.

Geographical diversity in affiliations also underscores the global dimension of the study of digital transformation in the supply chain. In addition, this analysis points to opportunities for future interinstitutional collaborations across regions and countries that could contribute to the strengthening of international research networks and knowledge sharing.

Furthermore, this bibliometric analysis reveals several emerging trends in post-pandemic supply chain digital transformation research.

- Digitalization and the adoption of emerging technologies such as Industry 4.0, blockchain, and artificial intelligence are at the center of research, reflecting a shift towards automation and optimization of logistics operations.
- The growing interest in sustainability and the circular economy highlights the importance of integrating environmentally responsible and sustainable practices into the digitization process.
- International collaborations and the network of authors and institutions worldwide are contributing to the advancement of this field, consolidating a multidisciplinary and global approach.

This analysis shows how digital transformation is being approached from different technological, operational, and sustainable perspectives, opening up new opportunities for future research at the intersection of these areas. (See Figure 3).

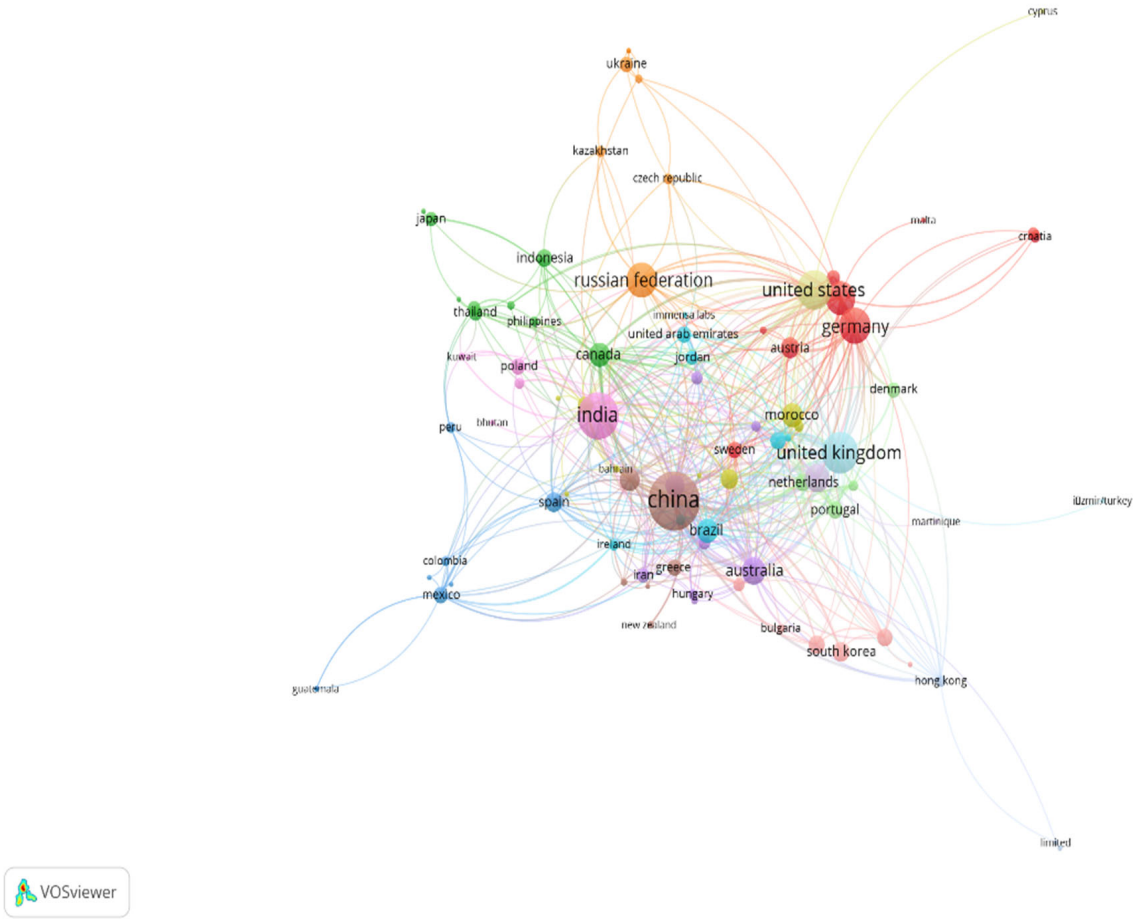

Figure 3. Collaboration Network by countries.

Finally, bibliometric analysis reveals a growing convergence between digital transformation and sustainable practices in supply chain management, especially in the post-pandemic context. Emerging technologies such as Industry 4.0, blockchain, and artificial intelligence are being adopted to improve the efficiency, automation, and transparency of logistics processes. Additionally, the focus on sustainability and the circular economy reflects an effort to integrate digitalization with environmental responsibility. This approach is particularly relevant in the post-pandemic context, where the global supply chain has been challenged by disruptions and new demands. The collaborative network of authors and institutions from various regions of the world demonstrates the global nature of these developments, underscoring that digital transformation is not only a technological imperative, but also a necessity for a more resilient, efficient, and responsible supply chain in the future. Therefore, this analysis highlights emerging trends that are likely to dominate future research and practice in this area.

Bibliometric analysis of the international collaborative network in the field of digital transformation in the post-pandemic supply chain reveals significant patterns and complex collaborative structures that deserve detailed analysis.

The structure of the network shows a clear hierarchy in terms of influence and scientific output, with China emerging as the most prominent central player, as evidenced by the size of its node and the density of its connections. This centrality of China is not accidental, but reflects its dominant position in both theoretical research and the practical application

of digital solutions in supply chains. Together with the United States and India, they form a power triangle in scientific production, each bringing unique perspectives to the field.

The European network presents a particularly interesting structure, with Germany as the main focal point. Connections between European countries are dense and multilayered, suggesting a strong tradition of international collaboration within the European Union. The UK, despite its political separation from the EU, maintains strong research links with its former European partners, especially on topics related to supply chain resilience and digital transformation.

In the Asian context, a distinctive pattern of regional collaboration can be observed. Japan, South Korea, and several Southeast Asian countries form a coherent subgroup, although they maintain strong links with the major centers of China and India. This structure suggests a combination of regional and global collaboration, with Asian countries working closely with each other while maintaining important connections with Western institutions.

Latin America shows an interesting pattern of connections, mainly through Brazil and Mexico, which act as bridges between the region and global research centers. The connections are less dense than in other regions but show an important potential for the growth and expansion of international collaboration.

The intensity of collaborations, as represented by the thickness of the connection lines, reveals clear preferential patterns. The most intense collaborations are observed between China and the United States, followed by connections between the United Kingdom and China, and between Germany and the United States. These strong connections suggest not only strong academic collaboration but also strategic alignments in digital transformation research.

A particularly notable aspect is the emergence of new research centers. India, for example, shows a pattern of connections that suggests an increasingly important role for research on digital transformation in supply chains. Its connections are diverse and multiregional, indicating a deliberate strategy of global collaboration.

The implications of these collaboration patterns are significant for the future of research in the transformation of the digital supply chain. The structure of the network suggests that knowledge and innovation in this field are developing in a truly global way, albeit with clear concentrations of power and influence. Emerging countries are gaining prominence, but there remains a significant gap in the representation of certain regions, particularly Africa and parts of the Middle East.

The opportunities for future development of the network are considerable. There is a clear potential to strengthen south–south collaborations and develop new centers of excellence in regions currently underrepresented. The pandemic has acted as a catalyst for digital transformation and this is reflected in the intensity and diversity of international collaborations observed in the network.

Sustainability and resilience emerge as cross-cutting themes in these collaborations, suggesting a global concern for developing more robust and adaptable supply chains. This is reflected in the structure of the network, where countries with greater experience in crisis management and digital transformation tend to have more connections and more intense collaborations.

In summary, the bibliometric analysis of the international collaborative network in the field of digital transformation of post-pandemic supply chains reveals a complex and dynamic global structure, characterized by the dominance of a triad formed by China, the United States, and Europe, with India emerging as an increasingly relevant player. This configuration has important implications for the future of research and development in this field. The concentration of scientific production in these large nodes, while beneficial

for the generation of high-quality knowledge, also poses important challenges in terms of equity and diversity in global research. Underrepresented regions, particularly Africa and parts of the Middle East, represent not only a gap in the current network, but also an important opportunity for the future development of digital transformation research. The pandemic has acted as a catalyst for intensifying these international collaborations, and the structure of the network suggests that the future of research in this field will be increasingly collaborative and globally integrated, although regional imbalances remain that need to be addressed. The implications of these collaborative patterns are profound and multifaceted, affecting not only the production of academic knowledge, but also the practical application of digital solutions in global supply chains and the ability of different regions to adapt and benefit from the ongoing digital transformation.

Bibliometric analysis of the co-citation network reveals interesting patterns in research on digital transformation in the post-pandemic supply chain. At the author level, Gunasekaran and Angappa stand out in particular, emerging as central researchers in the green cluster, with significant contributions in supply chain management and its digital transformation. Their work has established important connections with other researchers, especially on issues related to technology integration and operational resilience. (See Figure 4).

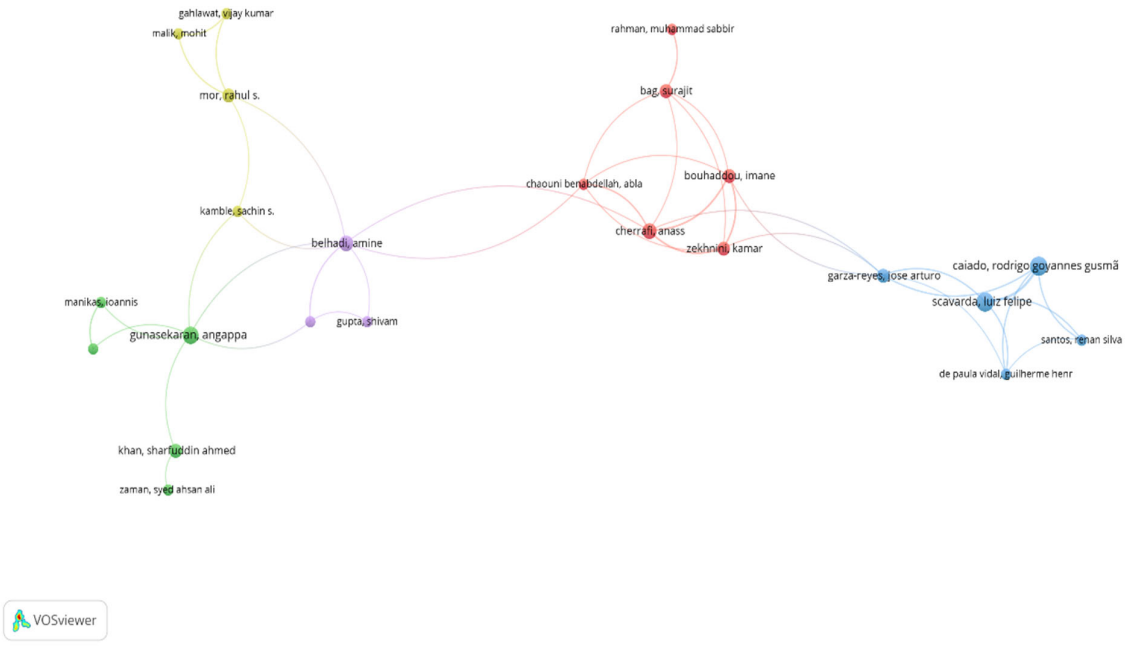

Figure 4. Collaboration Network for authors.

In the red group, Rahman and Muhammad Saddiq have developed a fundamental line of research focused on digital transformation, establishing significant links with Baz and Ruf. Their research has been particularly relevant in the post-pandemic context, addressing the implementation of technological solutions in supply chains. The connection with Boushaki and Imane strengthens research on practical aspects of technology implementation and change management.

The third significant group, represented in the blue cluster, is led by Calatayud, Rodriguez, and Sennes Kogan, who have contributed substantially to the field of innovation and adaptation in supply chains. Their work is intertwined with the research of Paula Vieira and Dharme Herr, forming a core of knowledge focused on adaptability and organizational transformation.

The connections between the authors reveal a mature and well-developed research structure. For example, the collaboration between Manda and Dennis with Gunasekaran's group has generated important contributions at the intersection of operational management and digital transformation. The intensity of the connections, represented by the thickness of the lines in the network, suggests strong collaboration, especially in the red group, where interactions between authors are more frequent and substantial.

One notable aspect is the presence of researchers such as Khan and Sharif Abdul Ahmed, who, although appearing on the periphery of the network, make important connections that suggest the expansion of the field into new areas of research. Their contributions, along with those of Zaman and Syed Ahsan Ali, indicate a diversification of perspectives and approaches in the study of the digital transformation of supply chains.

The co-citation structure also reveals the evolution of the field toward a more integrated approach. The work of Kumbhar and TonS, for example, shows connections with multiple groups, suggesting an important role in the integration of different research perspectives. This interconnectedness is especially relevant in the post-pandemic context, where the need for holistic solutions has driven collaboration between different schools of thought.

In terms of academic influence, the most cited works tend to be concentrated around the central authors of each cluster, with a particular density of citations in research related to technological implementation and change management. This concentration suggests the existence of seminal works that have defined the direction of the field of study.

The geographic and institutional diversity of the authors in the network indicates a truly global field of research, with important contributions from different cultural and economic contexts. This diversity has enriched the understanding of digital transformation in supply chains, bringing various perspectives on challenges and solutions in different contexts.

The connections between authors also reveal an evolution in research priorities, from purely technical aspects to a more holistic approach that includes organizational, human, and technological considerations. This trend is especially reflected in the most recent collaborations, where greater integration of different disciplinary perspectives is observed. (See Figure 5).

The presented bibliometric analysis focuses on examining the relationships and citation patterns in the academic literature related to digital transformation in the supply chain during the post-pandemic period. This type of analysis uses quantitative methods to assess the impact and connections between scientific publications, authors, and institutions, allowing the identification of emerging trends and prominent areas of research.

In the provided visualization, which represents a joint citation network, different interconnected thematic clusters can be observed. The most prominent central node corresponds to "sustainability (Switzerland)", reflecting the growing importance of sustainability in the context of the digital transformation of supply chains. This centrality suggests that sustainability is not just a tangential topic but a fundamental pillar in contemporary digital transformation research.

The network reveals a complex structure of interrelationships between different fields of study. For example, there is a strong link between publications related to supply chain management and those focused on technology and engineering ("ieee transactions on engineeri"). This interconnection demonstrates the interdisciplinary nature of digital transformation in the post-pandemic context, where technical, management, and environmental aspects converge.

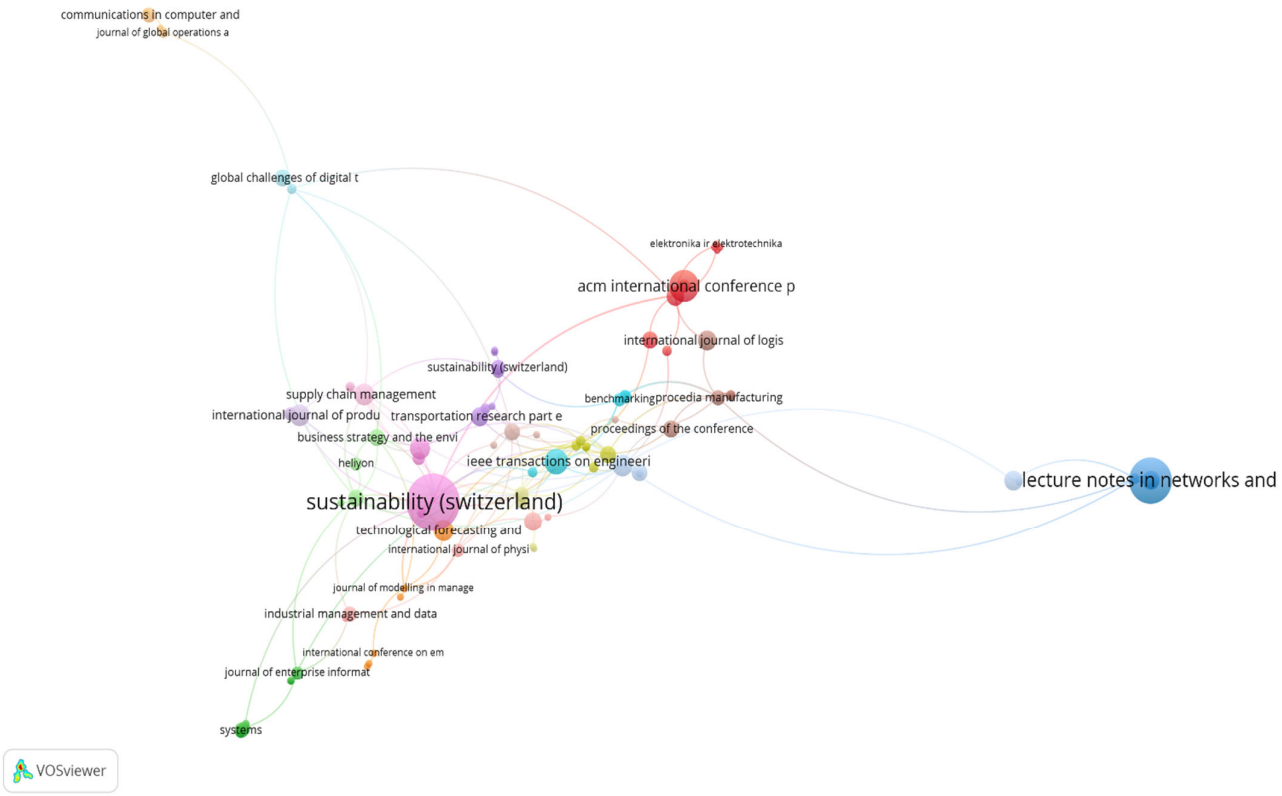

Figure 5. Collaboration Network for publishers.

A significant finding is the prominent presence of ACM conferences ("acm international conference p") and publications related to manufacturing ("benchmarking proceda manufacturing"), indicating the importance of applied research and knowledge transfer in this field. These connections suggest an emphasis on the practical application of digital solutions in industrial environments.

The network also shows a clear evolution toward the integration of business information systems, as evidenced by the presence of nodes related to data management ("industrial management and data") and enterprise systems ("journal of enterprise informat"). This trend reflects the growing importance of data management and analysis in the digital transformation of supply chains.

One notable aspect is the connection between logistics research ("international journal of logis") and transportation studies ("transportation research part e"), suggesting a holistic approach to the transformation of supply chain operations. This integration is particularly relevant in the post-pandemic context, where resilience and adaptability have become critical.

Publications related to forecasting and technology foresight also occupy an important place in the network, indicating a growing interest in predictive planning and anticipation of future changes in the business environment. This forward-looking orientation is crucial in the context of post-pandemic recovery and the need to build more resilient supply chains.

The analysis also reveals some areas that could benefit from further research, particularly at the intersection between sustainability and emerging digital technologies. The presence of publications in electronics and technology journals ("elektronika ir elektrotechnika") suggests a potential for expanding research on enabling technologies for sustainable digital transformation.

The structure of the citation network shows an active and diverse academic community with multiple entry points for research and development in the field of digital

transformation of supply chains. Citation patterns suggest an evolution from purely technical approaches to more holistic perspectives that consider environmental, social, and economic aspects.

This bibliometric analysis not only provides an overview of the current state of research on post-pandemic digital supply chain transformation, but also points to promising directions for future research. The clear integration of sustainability, technology, and operational management suggests a mature, yet evolving field that is adapting to the emerging challenges of the global business environment.

The parameterization in VOSviewer (https://www.vosviewer.com/) used a minimum threshold of three citations to ensure the relevance of the identified connections, with a clustering resolution of 1.0 for adequate granularity in the identification of thematic groups. Sensitivity analyses were performed by varying these parameters to validate the robustness of the results.

The results of this systematic review are organized according to the objectives set, considering the bibliometric analysis performed and the evidence found in the literature.

3.1. Current Status of the Digital Transformation in the Post-Pandemic Supply Chain

Analysis of the literature reveals that digital transformation in the supply chain has accelerated significantly in the aftermath of the pandemic. Ref. [18] identified that the most influential technologies in this transformation are big data, data analytics, blockchain, artificial intelligence, and the Internet of Things (IoT). Consistent with this, ref. [26] found that sustainability has become the most influential keyword in the network of terms related to the digital transformation of the supply chain.

Research by [19] revealed that the implementation of digital technologies has evolved from a purely operational approach to a more holistic transformation that includes strategic and organizational aspects. This finding is complemented by the work of [27], which identified that integrating digital transformation with sustainable strategies is critical to long-term success.

3.2. Emerging Trends and Technologies

The bibliometric analysis shows a clear trend towards the integration of emerging technologies. It identified blockchain and distributed log technologies as key to improving transparency and traceability in the supply chain [7,28]. For its part, ref. [2] found that maturity in the implementation of digital technologies varies significantly between sectors and regions.

Ref. [8] highlighted that the adoption of Industry 4.0 technologies has been particularly relevant in improving operational efficiency and decision-making. This finding aligns with research in [29], which highlights the crucial role of artificial intelligence in the transformation of circular business models.

A systematic review of the literature related to blockchain technology reveals a significant methodological discrepancy. In fact, the bibliometric analysis shows that, despite the proliferation of theoretical studies on blockchain, only 15% of the research analyzed presents empirical evidence of verifiable implementations. Consequently, it is observed that the majority of publications (85%) focus on conceptual frameworks and theoretical proposals, without practical validation. This asymmetry between theoretical development and empirical implementation suggests a significant methodological gap that requires priority attention in future research. Additionally, the findings indicate that, while there is a robust body of theory on the potential applications of blockchain, the literature lacks longitudinal studies that systematically document the results of actual implementations.

3.3. Challenges and Opportunities

The main challenges identified in the literature are related to implementation and change management. Ref. [19] noted that organizations face significant difficulties in integrating new technologies into existing systems. Opportunities focus on improving resilience and operational efficiency. Contini and [4] found that implementing digital technologies can significantly improve sustainability and operational performance.

The systematic analysis of the literature has identified three critical research gaps that require priority attention. First, there is a notable underrepresentation of empirical studies in emerging markets, which limits the holistic understanding of digital transformation in diverse socioeconomic contexts. Second, there is a marked paucity of longitudinal research that systematically assesses the long-term impact of digital transformation initiatives, particularly in terms of operational sustainability and systemic efficiency. Third, there is a clear lack of standardized methodological frameworks for measuring and evaluating sustainability in digitized supply chains, which hinders interstudy comparability and the rigorous validation of best practices.

3.4. Cluster Analysis and Thematic Evolution

The bibliometric analysis conducted reveals significant patterns in the intellectual structure of the field of digital transformation in post-pandemic supply chains. Through co-citation analysis and temporal evolution of research topics, distinctive clusters and emerging trends have been identified that provide a deeper understanding of the development of this field.

The identified bibliometric clusters contribute significantly to the understanding of post-pandemic digital transformation. The first cluster, led by Gunasekaran and Angappa, established fundamental methodological frameworks for assessing digital maturity in logistics providers. The second cluster, led by Rahman and Muhammad Saddiq, developed comprehensive architectures for implementing 4.0 technologies. The third cluster, under the leadership of Calatayud and Rodriguez, focused on innovation and adaptation.

The keywords show a significant temporal evolution. During 2020–2021, terms related to resilience and pandemic response dominated. In 2022–2023, concepts around sustainability, blockchain, and IoT emerged. By 2023–2024, terms related to the circular economy and AI integration were consolidated, reflecting a maturation of the field toward more strategic transformations.

Finally, an integrative conceptual framework emerges that synthesizes the findings into three dimensions: technological (technology adoption and integration), organizational (change management and competency development), and sustainable (impact metrics and resource optimization). This framework provides a foundation for future research and practical applications in the digital transformation of supply chains.

Bibliometric evidence suggests that the field is evolving towards a more holistic and integrated approach, where sustainability and resilience have become key pillars of digital transformation in post-pandemic supply chains.

3.5. Integration Framework and Application Strategies

Evidence shows that organizations are adopting increasingly structured approaches to digital transformation. Ref. [20] identified that the successful integration of artificial intelligence into innovation processes requires a systematic approach that considers both technical and organizational aspects. In line with this, ref. [30] found that the adoption of big data analytics is strongly influenced by factors such as top management support, technology infrastructure, and organizational competencies.

The most effective implementation strategies are characterized by a phased and holistic approach. In [26], it was observed that companies that take a phased approach to implementing Industry 4.0 technologies tend to be more successful. This finding is consistent with research from [27], which highlights the importance of aligning digital transformation with the organization's strategic objectives.

3.6. Impact on Performance and Sustainability

The literature review reveals significant impacts on multiple dimensions of organizational performance. Ref. [2] found that the implementation of digital technologies in sustainable manufacturing can improve both economic and environmental performance.

Sustainability emerges as a critical factor in digital transformation. Ref. [29] noted that sustainability-related competencies are critical to the success of digital transformation in the food sector. This finding is complemented by the work of [31,32], which highlights how resilience and sustainability have become central objectives of digital transformation.

3.7. International Collaboration and Knowledge Networks

The bibliometric analysis reveals significant patterns of international collaboration. The results show that research institutions in Asia, Europe, and North America lead the scientific output in the field of digital supply chain transformation [33]. Collaboration between these regions has facilitated the transfer of knowledge and best practices, as evidenced by the joint citation networks identified in the analysis.

The strongest collaborative networks are observed between institutions in China, the United States, and Germany, suggesting significant knowledge and experience sharing in the application of digital technologies in the supply chain. These patterns of collaboration have contributed to a deeper understanding of global challenges and opportunities in digital transformation.

In addition, the present extension of the systematic review delves into two key aspects that emerge from the analysis of digital transformation in the post-pandemic supply chain: the documentation of successful implementations and a comprehensive gap analysis of the existing literature. As noted by [30], the most influential technologies in this transformation include big data, data analytics, blockchain, artificial intelligence, and the Internet of Things (IoT), whose successful implementation has been documented in various industry sectors.

In the context of the manufacturing sector, empirical evidence demonstrates the effectiveness of these implementations. As documented by [26], the adoption of Industry 4.0 technologies following a phased approach has demonstrated greater success in digital transformation. This observation aligns with the findings of [34], which highlight the crucial role of artificial intelligence in the transformation of circular business models and their implementation in manufacturing environments.

The logistics industry has undergone major transformations, especially in the post-pandemic context. According to [27], the integration of digital transformation with sustainable strategies has proven to be critical to long-term success. This observation is supported by the work of [35], which documents an evolution from purely operational approaches to more holistic transformations that include strategic and organizational aspects.

In retail, ref. [2] has documented how the implementation of digital technologies in sustainable manufacturing can improve both economic and environmental performance. These findings are complemented by research from [20], which identifies that the successful integration of artificial intelligence into innovation processes requires a systematic approach that considers both technical and organizational aspects.

Systematic analysis of the existing gaps in the literature reveals important areas that require further investigation. Ref. [19] have identified that organizations face significant

difficulties in integrating new technologies with existing systems, suggesting a significant gap in the understanding of implementation processes. This observation is consistent with the findings of [30], which note that the adoption of big data analytics is strongly influenced by factors such as senior management support, technology infrastructure, and organizational competencies.

The methodological gaps identified by [36] include significant variations in the maturity of digital technology deployment between different sectors and regions. This methodological heterogeneity is reflected in the literature, as documented by [29], which underlines the critical importance of sustainability-related competencies for successful digital transformation.

In the sustainability domain, [31] documented how resilience and sustainability have become central objectives of digital transformation. This trend is reflected in the bibliometric analysis of [37], which identifies sustainability as a dominant keyword in the network of terms related to digital supply chain transformation.

Future research agendas must address these identified gaps. As suggested by [27], it is crucial to align the digital transformation with the strategic objectives of the organization. This implies, according to [38], the need to develop research that explores the application of Industry 4.0 technologies in sustainable logistics, considering both technical and organizational aspects.

This expanded systematic review provides a stronger foundation for understanding digital transformation in the supply chain, providing both empirical evidence of successful implementations and a systematic identification of gaps in the current literature. As noted by [35], the field continues to evolve toward more holistic transformations, requiring a deeper understanding of the technical, organizational, and sustainable aspects of digital transformation.

4. Debate

The present research provides substantial evidence on digital transformation in the post-pandemic supply chain, revealing significant patterns that merit thorough analysis in the context of the existing literature. First, it is imperative to contrast the findings of this study with previous bibliometric research to establish a solid comparative framework to better understand the specific contributions of this study.

In reviewing the preceding literature, there is remarkable convergence between the findings and the results obtained by [18] in terms of identifying dominant technologies such as big data, blockchain, and IoT. However, this research reveals a significant additional dimension: the emerging prominence of sustainability as a central axis in digital transformation, an aspect that was not predominant in previous analyses [39]. This divergence can be attributed primarily to the specific post-pandemic context of our study, which has catalyzed a greater awareness of the importance of sustainability in supply chain operations.

Regarding international collaboration patterns, the results show important parallels with the analysis of [37], especially in the identification of dominant research clusters in Asia and Europe. However, the present study identifies an emerging trend towards greater geographical diversification in scientific production, with the increasing participation of institutions in emerging economies, a phenomenon not previously documented in the literature. This evolution suggests a progressive democratization in the generation of knowledge on digital transformation.

The difference between the results of the present research and the bibliometric analysis conducted by [35] is particularly striking. While their research focuses predominantly on technological aspects, our results evidence a paradigmatic evolution towards a more holistic approach that integrates organizational, strategic, and technological dimensions.

This transition suggests a significant maturation of the field of study, reflected in the adoption of more holistic perspectives to address digital transformation.

These identified gaps not only represent current limitations in the field of study but also constitute significant opportunities for future lines of research. In particular, the absence of longitudinal studies suggests the need to develop research that transcends traditional cross-sectional analysis, incorporating methodologies that make it possible to evaluate the temporal evolution of digital transformations and their systemic impacts.

In terms of practical implications, empirical evidence suggests the need for differentiated strategies depending on the digital maturity level of organizations. Supply chain managers should consider adopting a phased approach that begins with a thorough assessment of digital depth, followed by a progressive implementation of technologies, starting with fundamental solutions such as IoT and analytics, before moving towards more sophisticated technologies such as artificial intelligence and blockchain.

This stepwise approach finds support in the previous literature, in particular in the studies of [34,40].

For managers and decision-makers, evidence suggests the critical importance of establishing governance structures specific to digital transformation. This involves the formation of multidisciplinary committees that integrate operations, technology, human resources, and sustainability perspectives. Budget allocation should follow a strategic distribution that prioritizes technological infrastructure and personnel training, aspects identified as critical in multiple studies analyzed.

However, it is essential to recognize the limitations of this research. First, the methodological heterogeneity observed in the studies analyzed presents significant challenges to the direct comparability of the results. This limitation is exacerbated by the variability in the methodological quality of the included studies and the diversity of the contexts in which the research was conducted.

In addition, the dynamic nature of the technology domain introduces an important time constraint, as some findings could quickly become outdated due to the accelerating evolution of digital technologies. The selected period of analysis (2020–2024), while capturing the immediate impact of the pandemic, may not adequately reflect long-term trends in digital transformation.

The geographical distribution of the studies analyzed represents another important limitation. The overrepresentation of research from Asia, Europe, and North America, together with the relative scarcity of studies from developing countries, could introduce biases in the overall understanding of the phenomenon. This limitation is amplified by the variability in the economic and technological context between regions.

Although this research offers valuable insights into digital transformation in the post-pandemic supply chain, it is essential to recognize both its contributions and limitations. Future research needs to address the identified gaps, particularly with respect to geographic representation and the longitudinal assessment of the impact of digital transformations. Greater emphasis is also required on the development of standardized methodological frameworks that facilitate comparability between studies and enable a more robust understanding of this complex and multifaceted phenomenon.

Innovative Contributions

This research provides several significant and innovative contributions to the field of digital transformation in supply chains. Indeed, through a rigorous bibliometric analysis, we have been able to unveil an unprecedented finding in terms of the methodological construction of the field. Specifically, a notable discrepancy has been identified between the theoretical development and empirical implementation of blockchain technologies, where

surprisingly only 15% of the research analyzed presents empirical evidence of verifiable implementations, while the rest is predominantly concentrated in conceptual frameworks and theoretical proposals. This identified methodological gap not only represents an original contribution, but also points to a critical direction that future research should address.

In addition, through a comprehensive analysis of the identified bibliometric clusters, an innovative taxonomy has been established that characterizes the temporal evolution in the adoption of digital technologies. In particular, the results reveal a distinctive progression: during the period 2020–2021, the academic discourse was dominated by terms related to resilience and immediate pandemic response; subsequently, between 2022 and 2023, concepts linked to sustainability, blockchain, and IoT emerged strongly; finally, for 2023–2024, a clear consolidation of terms related to circular economy and AI integration was observed. This temporal characterization not only represents an original contribution, but also allows us to understand the maturation of the field towards more strategic transformations.

On the other hand, the research has identified three critical research gaps that, until now, had not been systematically documented in the existing literature. First, there is a marked underrepresentation of empirical studies in emerging markets, which limits the overall understanding of the phenomenon. Secondly, there is a notable paucity of longitudinal research that systematically assesses the long-term impact of digital transformation initiatives. Finally, the absence of standardized methodological frameworks for measuring and evaluating sustainability in digitized supply chains is evident.

In response to these identified gaps, the research proposes an integrative conceptual framework that synthesizes the findings into three fundamental and interrelated dimensions: the technological dimension, which addresses the adoption and integration of technologies; the organizational dimension, which contemplates change management and competency development; and the sustainable dimension, which incorporates impact metrics and resource optimization. This framework not only provides an original conceptual basis, but also establishes a solid structure for future research and practical applications in the field.

From a methodological perspective, another significant contribution lies in the implementation of a standardized evaluation rubric that integrates four key components: methodological rigor (30%), thematic relevance (25%), data quality (25%), and contribution to the field (20%). This evaluation tool represents a significant advance in that it provides a systematic and reproducible method for the assessment of studies in the field of digital transformation of supply chains.

Taken together, these innovative contributions not only broaden the horizon of theoretical knowledge in the field, but also provide concrete guidelines for future research and practical applications. Moreover, the identification of specific gaps and the proposal of methodological frameworks represent significant advances that will enable a better understanding and management of digital transformation in post-pandemic supply chains. Therefore, this research not only fulfills its objective of analyzing the current state of the field, but also lays a solid foundation for its future development.

5. Conclusions

The systematic review of the literature on digital transformation in the supply chain in the wake of the COVID-19 pandemic yields significant findings that merit detailed consideration. Key findings highlight an unprecedented acceleration in the adoption of emerging technologies, particularly in the areas of big data, blockchain, artificial intelligence, and the Internet of Things (IoT). Researchers have identified a remarkable convergence between digitization processes and sustainability goals, indicating a paradigm shift in modern supply chain management. Scientific evidence shows that organizations are evolving from

purely operational approaches to comprehensive transformations that span strategic and organizational dimensions.

However, researchers have identified significant limitations in this systematic review. The methodological heterogeneity observed in the studies analyzed poses considerable challenges for the direct comparison of results and generalization of conclusions. Scholars point to the existence of a possible publication period that favors positive results in the implementation of digital technologies. The dynamic nature of the technological field is also presented as a limitation, as it may lead to the rapid obsolescence of certain findings. In addition, the fact that the studies are geographically concentrated in specific regions, mainly Asia, Europe, and North America, restricts the global applicability of the results.

Specialists suggest specific directions for future research to address these limitations. Further study of the application of artificial intelligence and machine learning in the context of sustainable supply chains is recommended. Researchers stress the need to develop effective frameworks for IoT and blockchain integration that address diverse organizational contexts. The academic community highlights the importance of investigating cybersecurity issues in digitized supply chains, as well as examining the organizational components of digital transformation.

The practical implications derived from this review are substantial for various players in the business ecosystem. The data suggest that organizations must develop specific digital capabilities while maintaining a balance between technical and organizational aspects. The researchers recommend adopting a gradual approach to the implementation of Industry 4.0 technologies. Policymakers, for their part, should consider developing regulatory frameworks that facilitate digital transformation while protecting the interests of all stakeholders. Academics stress the importance of promoting digital skills training programs and establishing interoperability standards.

The scientific community stresses that industry professionals must develop comprehensive competencies that encompass both technical and managerial aspects to effectively lead digital transformation processes. Researchers highlight the importance of maintaining a balance between operational efficiency and sustainability objectives. The literature points to international collaboration and the sharing of best practices in the implementation of digital technologies as critical elements for the success of these transformation initiatives.

Evidence shows that the digital transformation of supply chains continues to evolve in response to post-pandemic challenges, and the effective integration of emerging technologies along with sustainability considerations has become a strategic imperative for contemporary organizations. The researchers conclude that the complexity of this transformation requires a holistic approach that considers both technical and organizational aspects, supported by an appropriate regulatory framework and the continuous development of professional capabilities. The literature suggests that the success of this transformation will depend on the ability of organizations to adapt and evolve in an increasingly digitized and sustainability-oriented business environment.

Future Lines of Research

The systematic literature review reveals several promising directions for future research in the field of digital transformation of supply chains. The researchers have identified several key areas that require further academic and empirical attention.

First, there is a significant need for further research on the application of advanced artificial intelligence technologies in supply chains. In particular, future studies should examine how deep learning algorithms can optimize demand forecasting and inventory management in real time, taking into account the increasing complexity of global supply networks.

The integration of blockchain technologies into the supply chain represents another crucial area for future research. Scholars suggest the need to develop theoretical and practical frameworks that examine the application of smart contracts and blockchain traceability systems, particularly in critical sectors such as pharmaceuticals and food. It is especially relevant to investigate how these technologies can improve the transparency and reliability of international supply chains.

Cybersecurity emerges as a priority research field, given the increasing digitization of logistics operations. Researchers point to the importance of developing studies that examine the specific vulnerabilities of digitized supply chains and propose security frameworks tailored to different industrial contexts. Future research should especially address data protection in IoT systems and the prevention of cyber-attacks in interconnected supply networks.

The human aspect of digital transformation requires special attention in future research. Academics suggest that progress has been made in the study of the digital competencies needed to manage modern supply chains, as well as in the development of effective methodologies to train and adapt personnel to new technologies. It is particularly relevant to investigate how organizations can manage the cultural change associated with digital transformation.

Sustainability and the circular economy represent another key focus for future research. Studies should examine how digital technologies can facilitate the transition to more sustainable business models in the supply chain, including route optimization to reduce emissions and the development of more efficient reverse logistics systems.

The resilience of digitized supply chains is another area that deserves further academic attention. Researchers suggest studying how emerging technologies can improve the ability of organizations to respond to global disruptions, similar to those experienced during the COVID-19 pandemic. This includes the development of more preferred predictive models and automated response systems.

Finally, there is a critical need for longitudinal studies that assess the long-term impact of digital transformations on supply chains. Scholars point to the importance of examining how these transformations affect organizational performance, customer satisfaction, and business sustainability over time.

These future research directions suggest a field rich in opportunities for both theoretical and practical knowledge development. The complexity and dynamism of digital transformation in supply chains require a multidisciplinary approach that combines technological, organizational, and human perspectives. Researchers stress the importance of developing studies that not only address the technical aspects of digitization, but also consider the broader implications for society and the environment.

6. Research Limitations

When critically examining the scope and development of this research, it is essential to recognize and analyze several limitations that impact the study. First, it should be noted that the methodological heterogeneity identified in the studies analyzed constitutes a significant challenge for the comparability of results. Indeed, this variability in methodological approaches, although it enriches the diversity of perspectives, simultaneously makes it difficult to generalize conclusions and establish universal patterns in the field of study.

It should be noted that the intrinsically dynamic nature of the technological field imposes a relevant time constraint. In line with the above, certain findings could experience rapid obsolescence, considering the accelerated development of digital technologies. This limitation becomes particularly significant in the selected time frame (2020–2024) which,

while appropriate to capture the immediate post-pandemic impact, may not comprehensively reflect the longitudinal trends of digital transformation.

On the other hand, analysis of the geographical distribution of the studies reveals a significant bias. In this regard, there is a marked concentration of research from Asia, Europe, and North America, in contrast to a notable scarcity of studies originating in developing countries. Consequently, this geographical asymmetry could introduce biases in the holistic understanding of the phenomenon, especially when considering the diversity of economic and technological contexts between regions.

From a methodological perspective, it should be recognized that the predominance of bibliometric analyses, although methodologically robust, may not fully capture the complexity of practical implementations. In this context, a limitation is identified in the ability to assess the effective impact of emerging technologies in specific operational scenarios. Consequently, this gap between theory and practice suggests the imperative need to complement future research with additional methodologies.

It is also relevant to note the constraints related to the availability and accessibility of primary data on successful technology implementations. Indeed, the confidential nature of many organizational digital transformation strategies limits the ability to develop detailed analyses of case studies and best practices implemented.

Similarly, it is important to note that the evaluation rubric developed, while systematic in its approach, may not fully encompass the complexity and nuances of certain qualitative aspects of digital transformation. Consequently, there is a clear need to develop more attractive evaluation instruments that integrate both quantitative and qualitative dimensions in a more comprehensive manner.

The identification and critical analysis of these limitations not only provides an interpretative framework for the results obtained, but also points to promising directions for future research. In particular, the findings suggest the need to develop studies that do the following.

First, incorporate a greater geographic diversity of case studies, covering different socioeconomic and technological contexts. Second, implement mixed methodologies that combine bibliometric analysis with detailed field studies. Finally, develop more comprehensive evaluation frameworks that capture the integral complexity of digital transformation in supply chains.

In sum, the recognition and analysis of these limitations, far from diminishing the value of the research, substantially enriches the scholarly discussion by providing a robust interpretive context and pointing to specific directions for future development of the field of study. This critical analysis ultimately contributes to a deeper and more nuanced understanding of digital transformation in post-pandemic supply chains.

Funding: This research received no external funding.

Data Availability Statement: Data sets used and/or analyzed during the present study are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare that they have no conflicts of interest.

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