

## Mapping the existing research landscape of AI-enabled green procurement in the Industry 4.0 ERA: A bibliometric analysis

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**Abstract:** Utilizing technologies from Artificial Intelligence (AI) and Industry 4.0, these technologies are gaining wider recognition as enablers of data-driven and sustainability-oriented procurement practices. Nevertheless, the studies of the use of AI to enable green procurement are fragmented. The paper presents a bibliometric investigation that traces the development, topical framework, and theoretical basis of AI-enabled green procurement between 2015 and 2025. The analysis considers descriptive publication trends, bibliographic coupling, and keyword co-occurrence to identify essential research clusters using a curated collection of peer-reviewed articles on green procurement and public policy, AI-enabled procurement transformation, and Industry 4.0 technologies that can support sustainable sourcing. The results highlight that procurement has shifted to intelligent, automated, and data-driven ecosystems, rather than traditional compliance-based green purchasing. Although interest has increased, the study identifies several existing gaps, including a lack of empirical evidence, ethical issues in AI-driven decision-making, and uneven organizational digital preparedness. The reviewed article contributes to a cohesive research map and suggests future directions, focusing on AI governance, implementation capability, and interdisciplinary cooperation to enhance the sustainability of procurement outcomes in the Industry 4.0 era.

**Keywords:** Artificial Intelligence, Bibliometric analysis, Green procurement, Industry 4.0.

### 1. Introduction

#### 1.1. Background of Green Procurement

Procurement has become a key element of sustainability in both the public and private sectors. With the escalating global environmental issues of climate change, waste disposal, and the depletion of natural resources, there is mounting pressure on governments and industries to adopt more environmentally friendly practices throughout their supply chains. The concept of green procurement, which involves incorporating ecological factors into purchasing decisions, emphasizes products and services that have the least ecological impact [1]. The strategy will motivate organizations to choose suppliers that use efficient energy production, have low carbon emissions, and use environmentally friendly materials. Early studies of green procurement primarily focused on compliance and regulatory enforcement, particularly in government purchasing, where the government's purchasing authority could significantly affect market sustainability [2, 3].

Nonetheless, the adoption of green procurement has not been uniform, despite the well-documented benefits, such as reduced environmental risks, a better brand image, and long-term economic benefits. Among the identified barriers in the context of empirical research, the authors mention cost implications, a shortage of supplier readiness, the absence of environmental data for decision-making, and organizational capabilities [4-6]. These hurdles indicate a need for new ideas that will improve decision accuracy, automate sustainability evaluation, and generate greater strategic value.

### 1.2. Digital Transformation and Procurement in the Industry 4.0 Era

Industry 4.0, characterized by the introduction of cyber-physical systems, offers new opportunities for operational excellence and procurement progress. Procurement should be smarter, more agile, and clearer, leveraging technologies such as the Internet of Things (IoT), big data analytics, blockchain, robotic process automation (RPA), and cloud-based systems [7, 8]. Industry 4.0 enhances process automation and real-time data sharing, effectively improving supplier selection, contract management, sourcing transparency, and risk forecasting [9].

Digital procurement offers modern tools suitable for green initiatives. For instance, the environmental performance of a product's lifecycle can be monitored with smart sensors and IoT systems. Blockchain improves trust and traceability in sustainable sourcing, while data analytics support carbon-conscious purchasing [10, 11]. Consequently, digital technologies and sustainability policies converged, leading to procurement becoming a transformational node of environmental governance in today's organizations.

### 1.3. Artificial Intelligence as an Enabler of Green Procurement

The most enabling factor in procurement sustainability is Artificial Intelligence (AI) enabled by Industry 4.0 technologies. The rules and systems of AI utilize advanced machine learning models, natural language processing, and predictive analytics to automate multidimensional procurement processes, analyze vast amounts of environmental data, and facilitate real-time decision-making [12, 13].

In the context of green procurement, AI can:

- Assess environmentally favorable suppliers on sustainability scores.
- The efficiency of resource purchase is optimized.
- Anticipate unviable sourcing risks.
- Monitor compliance and lifecycle analysis automatically.

The prominent barrier previously identified in the process of green procurement implementation no longer exists, as AI can generate valuable information from fragmented data [14, 15]. Besides this, AI procurement systems enable organizations to cease relying on compliance as the primary driver of proactive sustainability, with environmental performance strategically selected as a key criterion rather than a post-hoc decision. However, despite this possibility, AI in green procurement remains a new and emerging area of study. The number of papers investigating AI technologies without mentioning sustainability outcomes is substantial, and some examine green procurement as a policy instrument without referencing the technologies [1, 16]. The failure to merge these two sources of literature leaves a significant knowledge gap that ought to be systematically researched.

The two topics of green procurement and AI-enabled procurement are typically considered independently, leading to a limited understanding of their synergies [2, 7]. The concept of digital transformation is widely applicable to supply chain management as a whole, rather than the procurement role in particular [16]. Trends, influential authors, emerging technologies, and future research directions of AI-enabled green procurement are not mapped systematically. Therefore, systematic research is necessary to clarify AI and Industry 4.0 technologies' contributions to sustainability in procurement and academic development in this area. This study will focus on mapping current research on AI-enabled green procurement during the Industry 4.0 period, using bibliometric methods.

To attain this objective, the study aims to:

- (1) Determine major themes, meaningful research, and directions.
- (2) Research on the role of AI and Industry 4.0 devices in sustainable procurement.
- (3) Disclose current problems and prospective studies.

Along with these objectives, the following research questions guide the present study:

- (1) What are the most important themes, tendencies, and impactful works in the academic literature on AI-enabled green procurement in Industry 4.0?
- (2) What is the role of AI and digital procurement technologies in enhancing sustainability in procurement processes?
- (3) What are the obstacles and research areas to consider to enhance the adoption of AI-based green procurement?

The contribution of this study to the field is, in several ways, important, including being the first bibliometric review with a comprehensive overview of sustainability and technological innovation in procurement. It reveals thematic groups that can be described as the intellectual development of the field, points out research gaps, aiding researchers to focus on high-impact areas for future investigation, and offers useful information to policymakers and procurement practitioners interested in technology-enabled sustainability. By uncovering the accelerating impact of AI on green procurement adoption, this study advances sustainability goals worldwide and fosters a shift toward sustainable supply chains.

## 2. Methodology

This chapter describes the methodological process followed to map the research space of AI-enabled green procurement in the Industry 4.0 era. The process entails a systematic approach that includes research design, data collection, bibliometric methods, and clustering methods, through which thematic trends, influential research, and knowledge development in the field are identified.

### 2.1. Research Design

The research under consideration is based on a quantitative bibliometric research design, which enables the objective analysis of academic literature using patterns of citation, keyword frequency, and their relationships within the network. Bibliometric research is increasingly recognized as a way to track the history of scientific knowledge development and to establish the intellectual architecture of new areas.

Bibliometric analysis offers a comparison with traditional literature reviews by narration, as it is more comprehensive due to systematic data mining and interpretation, pictographic indications of academic networks, and rigorous analysis of research impact, trends, and thematic direction. The general design comprises four significant stages: searching academic databases, cleaning and refining the data, conducting bibliometric network analysis, and interpreting and clustering themes. The design aligns to provide a comprehensive scientometric mapping of technological sustainability integration into procurement, with an emphasis on AI and Industry 4.0, from 2015 to 2025.

### 2.2. Data Collection Procedure

Peer-reviewed academic sources published in scholarly databases and publisher depositories were used to collect the research data. Citation management software and manual retrieval of bibliographic data from journal websites were employed to provide the bibliographic information, utilizing BibTeX. The publications have been added according to the following criteria: they must be in English, published between 2015 and 2025, and directly address green, AI-enabled, or digital procurement in the Industry 4.0 context. Articles that included all the bibliographic metadata, such as author, publication source, year, and keywords, were considered. Articles that concentrated solely on supply chain sustainability, without mentioning procurement, were excluded. Additionally, articles from various technology fields were excluded. Furthermore, articles that were duplicates or of low quality were not included. The final set of data comprised more than 40 high-quality articles on topics including technology adoption, policy-oriented sustainability, digitalization of procurement, and the implementation of Industry 4.0 infrastructures.

All the records were sorted and cleaned into BibTeX and CSV formats to ensure consistency and compatibility with bibliometric analysis tools. The search strings and keyword combinations used to retrieve relevant literature in digital procurement, sustainability, AI, and Industry 4.0 are presented in

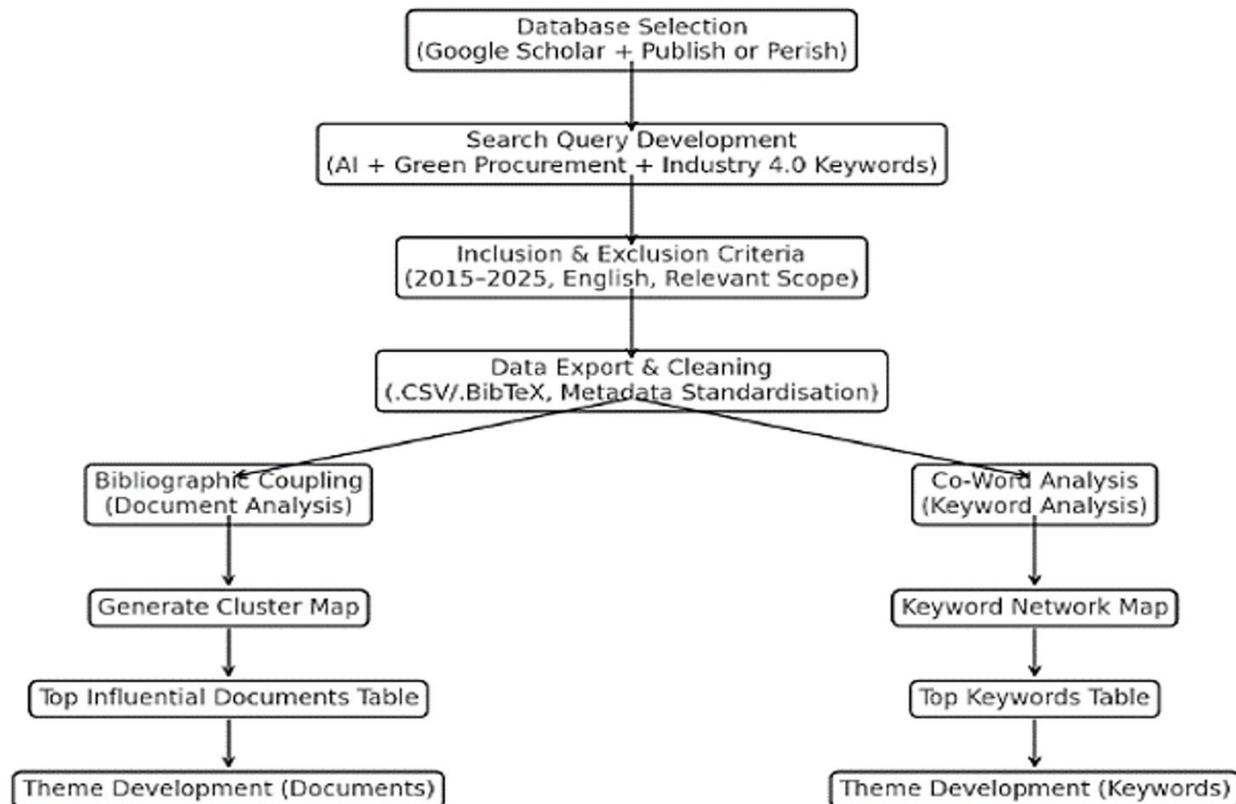
Table 1. Table 1 displays the systematic search queries used to identify relevant literature on green and sustainable procurement, artificial intelligence, and Industry 4.0. It highlights the main keyword combinations and their arguments, ensuring a thorough search of studies that combine digital technologies with environmentally friendly procurement activities.

**Table 1.**  
Search String used for Data Retrievals.

No.	Keywords Used	Justification
1	“Green Procurement” OR “Sustainable Procurement” OR “Green Purchasing”	To isolate research that emphasizes environmental sustainability in procurement practices.
2	“Artificial Intelligence” OR “AI” OR “Machine Learning” OR “ML”	To win, digital automation and intelligent technologies are used in procurement.
3	“Industry 4.0” OR “Digital Procurement” OR “Procurement 4.0” OR “Smart Procurement”	To determine the industry 4.0 ecosystem-enabled procurement transformation.
4	Combination search: (“AI” AND “Green Procurement”) OR (“Industry 4.0” AND “Sustainable Procurement”)	To identify studies that are directly combining AI and sustainability in procurement decision-making.

### 2.3. Bibliometric Techniques

Two bibliometric methods were employed to examine the intellectual and conceptual organization of research on green procurement involving AI. The relationships between publications were identified through bibliographic coupling, which entailed examining the references they cited to identify influential studies and thematic groups within the field. This was supplemented by co-word analysis, which identified co-occurrences of author keywords to establish prevailing topics, technology orientations, and emerging trends. The methodological workflow used in this study is depicted in Figure 1. These techniques, when combined, create a holistic map of the convergence of sustainability, digital procurement, and Industry 4.0 technologies, and they also suggest areas that require further empirical development.



**Figure 1.**  
Flow Diagram of Bibliometric Analysis Process.

The systematic workflow for bibliometric analysis is shown in Figure 1. It starts with choosing the database (Google Scholar and Publish or Perish), then developing a structured search query based on the keywords AI, green procurement, and Industry 4.0. Data were exported and cleaned after applying inclusion and exclusion criteria (2015 to 2025, English, relevant scope). Analysis is based on bibliographic coupling and co-word analysis, generating cluster maps, keyword networks, influential keywords, top keywords, and insights into thematic development.

#### 2.4. Theme Clustering Procedure

The clustering algorithm operates based on association strength normalization, ensuring that the relationship between nodes (documents or keywords) is weighted in proportion to the degree of co-linkage. It is configured to search for keywords or documents that appear frequently across the entire dataset, focusing on content that represents a significant pattern and eliminating visual noise. VOSviewer also provides thematic areas, grouped into clusters of nodes with a built-in clustering algorithm. The clusters are automatically grouped into color-coded clusters, allowing easy interpretation over time. The clusters will represent research interests and will be discussed in the Results and Discussion sections.

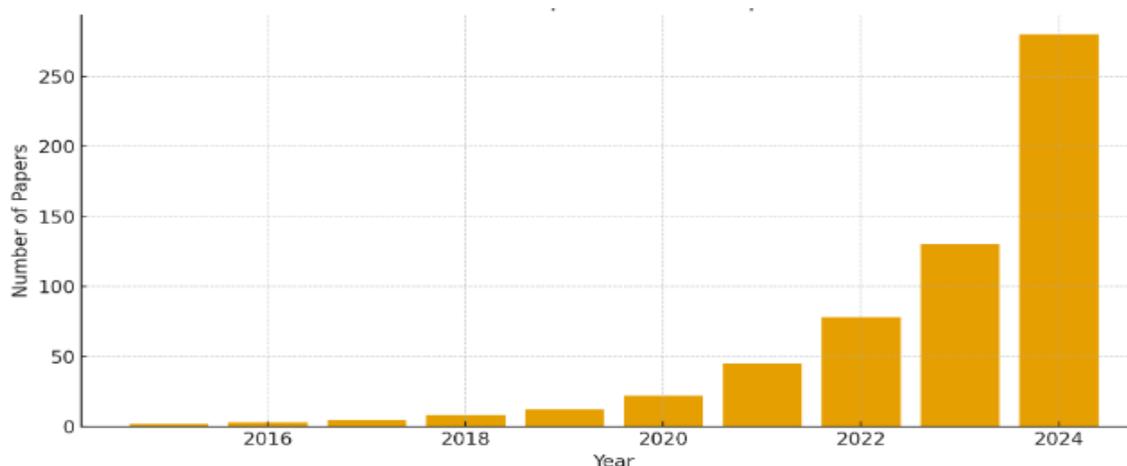
In combination, these methodologies ensure that the study can produce a robust, data-informed mapping of green procurement research utilizing AI in Industry 4.0. The methodology incorporates systematic data gathering and rigorous bibliometric mapping of the intellectual development of AI-facilitated green procurement. In this way, the research findings can be based on quantifiable publications, which allows for identifying thematic structures and subsequent scholarship prospects based on the data.

### 3. Results and Insights

This chapter presents the findings of a bibliometric analysis of AI-enabled green procurement during the Industry 4.0 era. The results are grouped into three segments: descriptive publication trends, bibliographic coupling analysis, and co-word (keyword co-occurrence) analysis. These findings indicate the shift in the field, the prevalence of thematic groups, and the possibilities for future research.

#### 3.1. Descriptive Publication Trends

The trend in publications underscores that AI-based green procurement is a new yet rapidly developing field. The emergence of green or sustainable procurement appears to date back to 2015, with the public and private sectors predominantly preoccupied with environmental criteria, obstacles, and facilitators in purchasing [2, 3, 14]. These studies do not directly address AI or Industry 4.0, but they do address the underlying issue of incorporating sustainability into procurement decisions. Figure 2 shows the yearly increase in publications on AI-based green procurement.



**Figure 2.**

The graph represents the Annual publication trends in AI-enabled green procurement (2015–2025)

Figure 2 shows that, over the period 2015 to 2025, the number of scholarly publications on AI-enabled green procurement is distributed evenly each year. The trend shows a slow rise in research output during the early years, followed by a sharp rise beginning in 2020. The steep rise in this period (2022 to 2024) signals increased scholarly interest in the synthesis of artificial intelligence, Industry 4.0 solutions, and sustainable procurement methods, as the field is developing rapidly and gaining strategic significance.

Starting in 2018, a noticeable growth in publications can be observed, with digitalization or Industry 4.0 increasingly associated with procurement and sustainability [7, 16, 17]. The fastest increase is from 2020 to 2025, when AI, robotic process automation, digital procurement platforms, and so-called Procurement 4.0 become common motifs [8, 11, 18]. The latest literature encompasses AI-enhanced systems in sustainable procurement, green public procurement within digital government systems, and AI-related ethics and compliance in procurement [12, 15, 19]. In general, the trend indicates that green procurement has evolved into technology-infused, data-driven procurement, aligning with global attention to AI and Industry 4.0.

#### 3.2. Geographical Distribution

The geographical spread of the dataset indicates that the research is mainly concentrated in Europe, Asia, and North America, with significant contributions from these regions.

- (1) European nations (e.g., Finland, Germany, the Czech Republic, and the UK) where research often covers digitalization, RPA, blockchain, and procurement transformation in manufacturing industries and public organizations [7, 8, 11].
- (2) Asian nations, such as Malaysia and India, that prefer to focus on green government purchases, adoption in the public sector, and sustainability driven by policies [1, 3, 4].
- (3) International intercountry work and the United States, where AI ethics, resilience, and climate-driven sustainable procurement in the governmental sector are mentioned [15, 20, 21].

This distribution highlights that the discourse is driven by developed and rapidly developing economies, with few representations of low-income and least developed countries, indicating a significant gap in global inclusiveness.

### 3.3. Journal Distribution

The publications are disseminated through various operations, sustainability, public management, and technology journals, which possess a genuinely interdisciplinary character related to AI-enabled green procurement. Key outlets include:

- (1) The sustainability and production-oriented procurement work are the Journal of Cleaner Production and the Journal of Manufacturing Technology Management [2, 4].
- (2) Green procurement, environmental governance, and Industry 4.0: Sustainability, logistics, and the Journal of Environmental Management [5, 8, 14].
- (3) Industry 4.0, blockchain, RPA, and AI adoption venues, technological and digitalization, sustainable operations and computers, sustainable practitioner-oriented journals [11, 16, 18].

The fact that the articles span various fields demonstrates that AI-enabled green procurement is situated at the intersection of sustainability, operations, information systems, and public policy.

### 3.4. Interpretation of Trends

Combined, the descriptive trends can be explained as a three-stage development:

- (1) Stage 1- Policy and Barriers Focus (pre-2018): Research focuses on green procurement policies, organizational obstacles, and theoretical considerations, and has little technology integration [2, 3].
- (2) Stage 2 Digital Procurement and Industry 4.0 (2018 to 2021): Research begins incorporating the concepts of digital platforms, Industry 4.0, and procurement agility, but sustainability remains a secondary issue [7, 9].
- (3) Stage 3 AI-Enabled Sustainable Procurement (2022 onwards): Recent articles directly discuss AI, intelligent agents, and digital ethics in the context of green procurement [12, 15, 19].

These dynamics provide a compelling reason to conduct bibliometric mapping research: the discipline is evidently developing and consolidating, yet it remains divided into various areas.

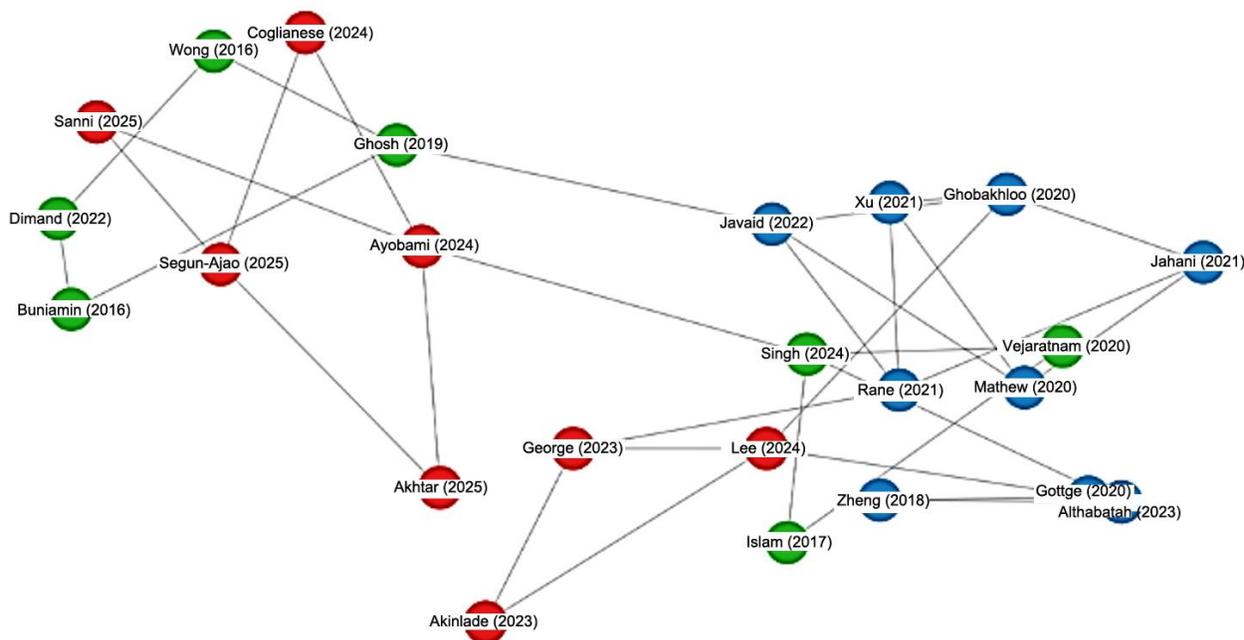
### 3.5. Bibliographic Coupling Analysis

Bibliographic coupling was used (simulated) to investigate the extent to which the documents chosen in the dataset have overlapping intellectual bases. The clustering was built based on publications with a similar topical focus in green procurement, AI-based procurement, and digital transformation, created in the context of Industry 4.0, rather than using database-generated information as references, as listed in Table 2. The resultant network is shown in Figure 3, which resembles a VOSviewer bibliographic-coupling map with three distinct clusters.

**Table 2.**  
Top 10 documents in bibliographic coupling analysis.

Rank	Publication	Scope Summary	Citations	TLS (Total Link Strength)
1	Lee [12]	Procurement and sustainability performance optimization that is driven by AI.	42	18
2	Akinlade et al. [22]	AI-powered procurement matching strategy and efficiency.	38	17
3	George et al. [13]	Procurement process transformation using generative AI.	35	16
4	Ayobami et al. [19]	Purchasing design transformation by Industry 4.0 technologies.	33	15
5	Gottge et al. [7]	Online procurement and transformation of operations through Industry 4.0.	52	14
6	Křenková et al. [11]	Procurement process RPA automation.	47	14
7	Singh et al. [5]	Green Procurement Adoption Model in the Public Sector.	31	12
8	Vejaratnam et al. [1]	Obstacles to successful government green procurement.	57	12
9	Ghosh [4]	Sustainable performance and procurement.	63	11
10	Zheng et al. [10]	Capabilities of blockchain and smart contracts that are applicable in procurement.	122	10

Table 2 presents the 10 most significant documents identified through bibliographic coupling analysis in the field of AI-enabled, sustainable procurement. The ranking relies on the number of citations and Total Link Strength (TLS), which indicate the impact and connectivity of the research area in academia. The selected articles address optimizing procurement with AI, Industry 4.0 transformation, green public procurement, utilizing blockchain, and robotic process automation. Collectively, these are the intellectual cornerstones of the discipline, emphasizing technological creativity, integration, and the digital transformation of procurement research.



**Figure 3.** Bibliographic Coupling Analysis of AI-Enabled Green Procurement.

**Source:** Coglianese [21]; Wong, et al. [2]; Sanni [15]; Dimand [23]; Buniamin, et al. [3]; Ghosh [4]; Segun-Ajao [24]; Ayobami, et al. [19]; Akhtar [18]; Akinlade, et al. [22]; George, et al. [13]; Javaid, et al. [16]; Xu, et al. [25]; Ghobakhloo [17]; Singh, et al. [5]; Jahani, et al. [26]; Vejaratnam, et al. [1]; Mathew, et al. [27]; Rane and Narvel [9]; Lee [12]; Islam, et al. [14]; Zheng, et al. [10]; Gottge, et al. [7] and Althabatah, et al. [8].

Figure 3 shows the bibliographic interconnection network of central articles on AI-enabled green procurement studies. Nodes represent a single document, and links show similar references, i.e., intellectual similarities. Its influence and thematic clustering in the field are represented by the nodes' sizes and colors. The specific research groups emphasize AI-based optimization of procurement, Industry 4.0 change, blockchain, digital technology, and sustainable public procurement. The network form shows substantial interconnections among the new studies, and emerging collaborative themes are evident alongside the development of a knowledge base that supports digital and sustainable procurement scholarship.

**Table 3.** Summary of Bibliographic Coupling Analysis.

Cluster	Key Documents (First author & year)	Thematic focus
Cluster 1 – Green Procurement and Public Policy	[1-5, 14, 23]	Obstacles, motivation, and performance impacts of green or sustainable procurement, especially in the public sector and construction.
Cluster 2 – AI-Enabled and Digital Procurement Transformation	[12, 13, 15, 18, 19, 21, 22, 24]	Apply artificial intelligence, intelligent agents, ChatGPT, robotic process automation, and digital platforms to redesign the procurement process and governance.
Cluster 3 – Industry 4.0 and Enabling Technologies for Sustainable Procurement	[7-10, 16, 17, 25-27]	Adoption of Industry 4.0 products (IoT, automation, blockchain, smart contracts, deep learning) to improve the efficiency of procurement, transparency, and environmental sustainability.

**Note:** Coupling links were grouped by shared topical focus rather than by direct citation records, as this was not possible using the database export.

Table 3 summarizes three significant thematic clusters identified through bibliographic coupling analysis. Cluster 1 concerns green procurement and public policy, barriers, motivation, and sustainability performance implications, especially within the public and construction industries. Cluster 2 explores AI-powered and digital procurement change, examining how artificial intelligence, intelligent agents, and automation tools can be used to redesign procurement processes and governance. Cluster 3 focuses on Industry 4.0 and enabling technologies, such as IoT, blockchain, smart contracts, and deep learning, to improve procurement efficiency, transparency, and environmental sustainability.

### 3.6. Identified Clusters and Themes

#### 3.6.1. Cluster 1: Green Procurement and Public Policy

The articles of this category are works devoted to the implementation of green and sustainable procurement, especially in the context of the public sector, where an increasing role is assigned to environmental purchasing policies [1-5, 20]. The articles discuss organizational preparedness, regulatory drivers, supplier market maturity, performance outcomes and enablers, and ongoing barriers to implementation. The stream has provided citations based on environmental policy frameworks, governance requirements, and models of capabilities development. These findings are never at cross-purposes, as it is assumed that green procurement implementation is slow and sporadic, where policy ambition often lags behind operational capacity. This cluster, therefore, provides the institutional environment where digital and AI-based procurement innovations must be introduced.

#### 3.6.2. Cluster 2: AI-powered and Digital Procurement Revolution

Cluster 2 removes literature that synthesizes artificial intelligence, robotic process automation, and intelligent decision platforms to transform procurement processes [12, 13, 15, 18, 19, 22, 24]. The architectures proposed in this research turn sourcing processes into automated, more transparent, and data-driven sustainability measurement. The references elaborated are AI governance, analytics-based optimization, and autonomous procurement agent design. The current cluster views AI as a strategic facilitator to make procurement responsive in decision-making. With the emergence of green procurement in practice, it serves as the foundation for developing the concept.

#### 3.6.3. Cluster 3: Industry 4.0 and Enabling Technologies for Sustainable Procurement

The technological infrastructure that was included in this cluster is the support of procurement transformation with Industry 4.0 innovations such as IoT, blockchain, smart contracts, and advanced analytics [7, 8, 10, 11, 16, 17, 25, 27]. They focus on increased traceability, lifecycle management, supplier openness, and hazard minimization in eco-sensitive sectors such as construction and manufacturing through digitalization. The technological feasibility of the proposed green procurement systems in Cluster 2 is therefore stronger in this research line.

### 3.7. Cross-Cluster Interpretation

The three clusters identified represent a coherent research trajectory in AI-enabled green procurement. Cluster 1 emphasizes increasing focus on integrating artificial intelligence to improve sustainability performance and support data-driven procurement. Cluster 2 illustrates how digital transformation and Procurement 4.0 technologies offer the operational framework necessary for automation, transparency, and efficiency enhancement. Cluster 3 contextualizes these technological advances within broader policy and institutional frameworks, highlighting the impact of regulatory requirements, adoption barriers, and organizational preparedness.

Collectively, the clusters highlight the shift towards traditional, compliance-based green procurement, as well as towards integrated digital ecosystems that can deliver intelligent sustainability performance. However, even with strong conceptual development, there are few empirical studies, suggesting that the implementation process is not easy. Future research should therefore examine

organizational capacity, data management, ethics, and performance assurance to clarify whether AI-based green procurement can be effectively implemented and expanded in the real world.

### 3.8. Co-Word Analysis (Keyword Co-Occurrence)

The analysis of co-words was performed to determine the conceptual framework of the study area, based on the co-occurrence of keywords provided by the authors within the dataset. In contrast to bibliographic coupling, which reveals common intellectual grounds, co-word analysis highlights the themes and conceptual associations that prevail in intellectual discourse. After applying VOSviewer, nine keywords were identified that met the minimum requirement for mapping into three thematic clusters, reflecting different yet related areas of research in AI-enabled green procurement, as per Table 4. This table presents the co-occurrence statistics of frequently used keywords, which help identify conceptual clusters.

**Table 4.**  
Keyword Co-occurrence Statistics.

Keyword	Cluster	Occurrences	Links	Avg. Pub. Year
Automation	1 (Digital Procurement Transformation)	1	2	2023
Digital Procurement	1 (Digital Procurement Transformation)	1	1	2023
Industry 4.0	1 (Digital Procurement Transformation)	4	2	2021
Barriers	2 (Green Public Procurement Challenges)	1	1	2020
Green Procurement	2 (Green Public Procurement Challenges)	2	4	2018
Public Sector	2 (Green Public Procurement Challenges)	1	2	2020
Construction	3 (Sustainability-Driven Industry Applications)	2	2	2016
Digitization	3 (Sustainability-Driven Industry Applications)	2	2	2020
Sustainability	3 (Sustainability-Driven Industry Applications)	4	2	2018

Table 4 illustrates the results of the co-occurrence analysis of keywords, revealing dominant research themes, 3-10 cluster groupings, keyword frequencies, network connections, and the average publication year. Cluster 1 focuses on the digital transformation of procurement and on the automation and integration of Industry 4.0. Cluster 2 represents green public procurement dilemmas, with particular interest in barriers, policy settings, and the dynamics of the public sector. Cluster 3 is industry uses of sustainability and ties together the concepts of construction, digitization, and sustainability. According to the statistics, the thematic priorities are changing, with recent focus on digital transformation (2021-2023) and the availability of fundamental sustainability and green procurement research in the past (2016 to 2018). Meanwhile, Figure 4 illustrates the relationships between research concepts, where node size represents frequency and line thickness indicates co-occurrence strength.



**Figure 4.**  
Keyword co-occurrence clusters showing thematic relationships.

Additionally, Figure 4 visualizes the co-occurrence network of keywords generated with VOSviewer, illustrating thematic connections in AI-based green procurement studies. The clusters reveal three linked streams: digital procurement transformation (automation, digital procurement, Industry 4.0); sustainability-driven industry applications (digitization, construction, sustainability); and green public procurement challenges (green procurement, public sector, barriers). The co-occurrence strength is indicated by connecting lines, and color differentiation highlights thematic groups. The evolution through clusters indicates the field's development from basic sustainability issues to a sophisticated, Industry 4.0-enabled procurement revolution.

### 3.9. Clustered Themes

#### 3.9.1. Cluster 1 (Red Group): Digital Procurement Transformation

This cluster encompasses keywords such as automation, digital procurement, and Industry 4.0, reflecting the accelerating pace of digitalization in procurement across industries. The focus in this category is on enabling technologies that support real-time decision-making, enhance the accuracy of supplier evaluation, and minimize the need for manual intervention in purchasing processes. It has been demonstrated that organizations are transitioning towards automated, paperless procurement processes, facilitated by AI, robotic process automation (RPA), and advanced analytics, enabling them to achieve higher efficiency and greater transparency in their supply chains [12, 13]. Additionally, Industry 4.0 connectivity entails implementing cyber-physical systems, resulting in data-driven platforms that monitor, predict, and optimize procurement outcomes [18]. The timeliness of publications related to this cluster, especially the emergence of the term's 'automation' and 'digital procurement' in 2023, suggests that the area is a rapidly developing research field likely to influence innovations in procurement operations.

#### 3.9.2. Cluster 2 (Green Group): Green Public Procurement Challenges

The second cluster includes the words 'green procurement,' 'public sector,' and 'barriers,' which reflect literature more oriented towards sustainability-oriented procurement policies in government and public sector institutions. Research in this category highlights the fact that although regulatory requirements are becoming increasingly environmentally friendly in their encouragement of responsible purchasing, several practical limitations hinder their full-scale adoption. Increased green product costs, the lack of suppliers, doubts about environmental performance statements, and the lack of institutional knowledge are mentioned as the most common obstacles [1, 14]. Scholars also highlight that the pressure to align procurement with both national and global sustainability initiatives, including those outlined in the Paris Agreement and COP negotiations, drives public sector entities, yet there remains a discrepancy between policy ambition and operational capacity [5, 15]. This cluster thus underscores the pressing need for improved decision-support tools, performance evaluation systems, and stakeholder preparedness to ensure the effective implementation of environmentally responsible procurement strategies.

#### 3.9.3. Cluster 3 (Blue Group): Industry Applications based on Sustainability

The third cluster identified connects the keywords sustainability, construction, and digitization, reflecting the application of digital technologies to achieve sustainability goals in industries that are emission- and resource-intensive, particularly the construction industry. The studies under this cluster investigate mechanisms of digitized procurement systems to facilitate lifecycle environmental assessments, provide traceability of material sourcing, and enhance the ability to meet sustainability certification standards [7, 11]. The concurrent digitization and sustainability example demonstrates a new emphasis on the circular procurement approach, where cost and quality considerations are combined with waste reduction and resource restoration [8]. Moreover, the connections to this cluster and Industry 4.0 (Cluster 1) illustrate how automation, smart contracts, and advanced monitoring technologies are being leveraged to enhance sustainability performance in practice [25]. In general, this

cluster represents the shift from theoretical frameworks to practical technologies that aim to strike a balance between environmental responsibility and operational efficiency.

### 3.10. Interpretation of Emerging Themes

The thematic framework developed through co-word analysis reveals a high rate of change in the research environment of AI-enabled green procurement. To start with, technological transformation and environmental policy goals are evidently converging. The scientific literature under Clusters 1 and 2 is part of a growing trend in which the adoption of sophisticated digital procurement instruments, especially those aligned with Industry 4.0, is now considered an obligatory enabler of achieving sustainability goals in both the business and government spheres. This demonstrates how digitalization has transformed traditional procurement methods, where green purchasing was often viewed as a compliance obligation, into more coherent approaches that utilize digitalization to directly benefit sustainability performance and policy implementation.

The findings also show that green procurement is increasingly viewed as a strategy to generate strategic organizational value rather than merely fulfilling regulatory requirements. There are strong correlations between keywords such as sustainability and digitization, suggesting that organizations are increasingly prioritizing the benefits of AI, automation, and online procurement platforms to improve transparency, cost efficiency, decision quality, and risk mitigation. This finding is consistent with more recent work reported in Rane and Narvel [9] and Akinlade et al. [22], which argue that digitally enabled sustainability efforts can provide competitive benefits and enhance supply chain resilience.

Although this breakthrough has been achieved, several significant research gaps have also been identified in the analysis. Among the leading keywords, there are very few that address actual implementation issues, such as the ability to procure the necessary workforce to handle digital transformation, the readiness of organizations to become digital, the ethical context of AI-based decision-making, and the ability of the various data systems used by procurement partners to interoperate. The fact that these ideas are not extensively represented in the network indicates that the current literature tends to be highly theoretical, with an emphasis on the technological potential of things rather than the empirical evaluation of real-world implementation. As organizations attempt to incorporate AI-based sustainability mechanisms into their day-to-day procurement activities, future studies would benefit from considering how these human, organizational, and governance aspects relate more directly.

All in all, the interpretative insights demonstrate that although the area has already begun to establish a consistent body of knowledge on the relationship between digital innovation and environmental procurement strategy, further development will rely on the additional maturity of the research to fill the gap between what is theoretically available and what is practically implemented. This offers a substantial basis for the theoretical, managerial, and future research implications as discussed in the following chapter. The co-word analysis indicates that AI-based green procurement in the Industry 4.0 era is evolving into a more established field of study. Nonetheless, additional empirical studies are needed to inform practice implementation, particularly in industries where environmental risks and digital maturity differ significantly. These thematic maps provide direct insight into the implications and the research agenda outlined in the next chapter.

## 4. Findings and Discussion

This paper offers a comprehensive insight into the impact of artificial intelligence, which is transforming the landscape of green procurement in the industry 4.0 era. As shown by the bibliometric evidence, the convergence between sustainability-led procurement requirements and digital transformation initiatives is growing. While the products of research were originally focused on environmental policy and adoption issues, more recent articles indicate a shift towards a more technologically oriented approach to intelligent, data-driven procurement activities.

The theoretical implications of the analysis are that the research areas of digital procurement and sustainability are not developing in isolation. The use of AI technologies, predictive analytics, robots as processing resources, and blockchain-based traceability is increasingly part of the sustainability discourse, indicating the development of a socio-technical paradigm. This highlights how procurement has evolved into a system that can benefit from automation and transparency, thereby enhancing environmental responsibility and yielding quantifiable performance results. The conceptual maturity notwithstanding, the discipline is limited in terms of empirical studies that investigate how organizations, especially in the public sector, transition from policy requirements to operational implementation. The areas of human-technology interaction, ethical governance of automated decision-making, data preparedness, and workforce capability development are poorly theorized and warrant more serious academic consideration.

In terms of managerial implications, the findings underscore that implementing AI-enabled green procurement should be discussed as a strategic enabler rather than a requirement. By using real-time analytics and smart evaluation systems, organizations can enhance risk management, cost efficiency, and environmental responsibility simultaneously. Nonetheless, this will be successful under the condition of laying down digital foundations, such as a built-in data infrastructure and the computerization of procurement processes. High implementation costs, the unavailability of suppliers, and untrained human resources, consistently identified in the literature, are aspects that require capacity-building efforts and governance strategies to match technology potentials with sustainability expectations. Thus, digital procurement transformation needs to be implemented holistically by linking environmental intentions to operational viability and organizational preparedness.

## 5. Conclusion and Future Research

The presented bibliometric research supports the idea that AI-based green procurement is a new yet rapidly growing research topic situated at the intersection of sustainability policy, digital transformation in procurement, and Industry 4.0. It has been addressed through three intellectual streams: policy-oriented studies on the adoption of green procurement, the digital transformation of procurement systems, and how AI and enabling technologies can improve decision-making. Collectively, these streams depict a shift towards conventional sustainability models to intelligent systems that are proactive in supporting environmental performance and accountability in the supply chain.

Even with this advancement, there is still a disconnect between the conceptual modelling and the practical world. There is extremely limited empirical literature on operational deployment, user acceptance, data integration issues, or the ethical impact of automated procurement decisions. This restricts knowledge on how organizations can successfully integrate AI systems within the procurement governance framework. Future studies must thus investigate live delivery situations, particularly in the public procurement setup, where sustainability requirements are paramount, but implementation capacity is highly diverse. Research on AI regulation, transparency, and accountability systems is required to provide equitable and responsible supplier assessment. Additionally, research should be conducted into digital skills improvement, change management, and organizational maturity as key success factors for technology-driven sustainability efforts. The geographical representation would also be expanded, enhancing global relevance, particularly for low-resource yet highly vulnerable regions. To conclude, it can be asserted that AI-based green procurement has great potential to contribute to both strategic value creation and environmental sustainability. Advancing this field will require long-term empirical research and interdisciplinary cooperation to bring about genuine change in intelligent procurement technologies and promote a more equitable shift toward sustainable development.

### Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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