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The Role of Green Risk Management Approaches in Promoting Green and Sustainable Supply Chain Management

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Abstract

This study assesses how advanced technologies like AI, blockchain, and big data facilitate green risk management in the automotive and electronics industries in the EU. When applied to environmental risk assessment, green purchasing, and eco-design activities, these technologies will optimize Economies of Scale (EoS) and contribute to advancing GSSCM in companies. This review uses systematic literature review and thematic analysis and focuses on using various peer-reviewed sources to understand how these technologies support GSSCM and also reveal gaps and challenges such as the integration of innovative waste disposal technologies and sustainable partnership schemes. Research proves that actual assessment of environmental risk is possible through the implementation of AI in risk assessment; On the other hand, blockchain makes sustainable procurement and reverse logistics more transparent. Thus, some problems like high costs, limited time, and problems with the alignment of stakeholder goals remain. It is recommended that these gaps be overcome by innovating, partnering with industries, and implementing policies that can further improve the position of information systems as the foundation of GSSCM. Thus, policymakers have been urged to explore options like grants or subsidies in an attempt to promote the adoption of these technologies as a way of creating a circular economy. Consequently, this research offers insights that may be beneficial for industry managers and policymakers seeking to improve sustainability within the EU automotive and electronics sectors.

Keywords:

Green risk management, sustainable supply chain management, information systems, artificial intelligence (AI), blockchain technology.

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Introduction

As more people become aware of environmental issues and with stricter legislative measures in the EU, most industries would adopt green risk management as the most vital area in building up GSSCM. Automotive and electronics are the two major areas whose growing demands cross borders to reduce ecological influence while maintaining operational efficiency (Schöggl et al., 2016). Green risk management, including environmental risk assessment and management, green purchasing and supply guidelines, and environmentally-friendly product and service design, has become a critical path to realizing these goals (Soo & Fernando, 2014). However, the efficiency of the management and those practices is improved to a higher level if implemented together with information systems.

Studies by Schöggl et al., (2016) and Soo & Fernando, (2014) have brought to light the imperative role that green risk management plays in achieving sustainable supply chain practices across the automotive and electronics sectors. According to Schöggl et al., (2016), the automotive and electronics sectors are now facing mounting pressures to minimize their footprints on the environment although improving efficiency in the process, requires an improved adoption of green risk management strategies. Meanwhile, Soo and Fernando show the role of practices like environmental risk assessment, green procurement, and eco-design in averting environmental footprints. Such studies provide foundational knowledge of the necessity for GSSCM response to regulatory demands besides growing environmental concerns in the European Union.

Recent literature points to the growing importance of information systems in the context of green risk management. Big data analytics, blockchain, and AI technologies are used to enhance supply chain management, make better decisions, and meet environmental standards. For example, big data analytics helps corporations gain insights from massive amounts of environmental data to assess risks and opportunities for change (Benzidia et al., 2021). In green procurement, blockchain technology brings the quality of transparency and workability in terms of ensuring the purchase of materials in an environment-friendly way. AI, however, is applied to develop environmentally sustainable products, besides ensuring proper utilization of resources throughout the product life cycle.

In this contrast, big data is actually applied in green risk management through specific applications within the automotive and electronics industries. Within the automotive sector for example, "BMW has been making use of big data analytics to monitor emissions real time across their manufacturing processes." Installation of sensors on production equipment by BMW has enabled timely notice of deviation from environmental regulation, hence timely corrective actions that have led to 15% reductions in carbon emissions in the last calendar year (BMW Group, 2023). In electronics, Philips Company employs big data in determining the effects of decisions in its supply chain, hence facilitating optimization of material sourcing and less waste. It has made significant improvements through the integration of big data analytics by Philips to ensure that the company complies with severe rules from the EU like the REACH directive, which requires suppliers to be environmentally fit, hence increasing transparency and sustainability in the supply chain. Clearly, these examples point out nicely how big data is directly applied to accomplishing sustainability goals through informed decision-making and environmental rule compliance.

The current study attempts to fulfil the research gap by testing the integration of cutting-edge information systems like AI, blockchain, and big data analytics in automotive and electronics-specific sectors in green risk management. Previous studies showed that sustainability is an important determinant; however, such a study might not contain a single-frame analysis of how such technologies can be used to overcome industry-specific challenges like managing high-tech waste or reverse logistics. Today, the automotive and electronics sectors form part of the biggest pollutants in the EU. There is a need to understand how these technologies can be used to enhance sustainability practices in those sectors to help meet broader environmental goals and regulatory requirements.

Research Questions

1. How do green risk management practices, supported by AI, blockchain, and big data, impact sustainability strategies in the automotive and electronics sectors in the EU?
2. What are the key challenges faced by these sectors in adopting reverse logistics and waste management technologies, and how can information systems help overcome them?

Literature Review

Introduction to Green Risk Management and Sustainable Supply Chain Management (GSSCM)

GRM and GSSCM are interrelated yet different concepts. GRM deals with the identification, evaluation, and risk elimination of environmental risks caused by the business, mainly pollution, waste, and resource depletion, for the reduction of negative impacts on the environment (Tronnebati & Jawab, 2020). GSSCM, on the other hand, combines principles of sustainability with the supply chain involving all stages from raw material acquisition to disposal at the end-of-life and achieves the delicate balance between a company's economic, environmental, and social objectives (Mangla et al., 2015). While GRM is set towards known risk and compliance, GSSCM targets developing a holistic sustainable supply chain to enhance long-term resilience and competitive advantage. Both are critical to companies' involving comprehensive environmental goals.

Changes in the culture of industries and sustainable supply chain management are crucial, especially in the EU, as most legislation related to the environment is strict. The automotive and electronics industries are one of the main pressures on reducing impacts on the environment while still performing efficiently (Mao & Shangi, 2023). Green risk management involves the use of environmental risk assessment toolkits, green purchasing, and environmentally friendly design strategies. They are designed as tools for evaluating and managing environmental impacts within value chains in a way to improve overall sustainability.

One of the latest developments in green risk management is the incorporation of information systems in organizational sustainability. New technologies like big data analytics, blockchain, and artificial intelligence have become effective enablers of supply chain operations, upgrade the decision-making process, and help meet environmental requirements (Song et al., 2022). Articles and journals in this section of the literature review seek to establish the relevance of the technologies in green risk management and their influence on GSSCM automotive and electronics industries within the EU.

Information systems will increasingly be an integral part of those firms that would like to implement effective green risk management through improving the capabilities of identifying, assessing, and mitigating environmental risks with high technologies. Notably, big data analytics will contribute significantly to green risk management by enabling an organization to analyze tremendous amounts of data on its environmental performance and sustainability. This technology allows the automotive and electronics sectors to make decisions based on data, monitor their environmental impact in real time, and adjust and reshape their procedures accordingly. By integrating these functionalities within a network, companies are therefore adhering to green supply chain strategies but also using them to bolster sustainability and resilience.

The Role of Information Systems in Green Risk Management

Big Data Analytics

With the help of big data analytics, green risk management utilizes tools for data analysis that are applicable to a large volume of data associated with environmental risks and sustainability. Manufacturing industries such as automotive and electronics produce big data throughout their supply chain processes including procurement, production, and sales among other activities (Mani et al., 2017). Remarkably, big data analytics helps organisations unlock this data to make informed decisions that prevent risks and spearhead sustainability initiatives across the business.

For instance, in the automotive sector, big data analysis may be employed to track emission levels at various production phases. An analysis made by Liu et al., (2017) has shown that the European automotive industry including BMW has incorporated big data analytics in their environmental risk management strategies. Real-time monitoring of emissions through sensors placed on manufacturing equipment helps BMW to identify any irregularities and take corrective measures that lower the impact on the environment. Likewise, in the electronics industry, big data analysis enables organizations, including Philips, to determine the environmental consequences of supply choices and where changes may be made to decrease environmental effects.

It also cites the application of big data analytics in increasing green procurement transparency and accountability. Bunzendahl & Papula, (2023) noted that big data helps companies assess supplier performance on environmental aspects to enhance compliance with sustainable procurement policies. This capability is of special relevance within the EU, given that legislation like the REACH directive established that firms need to substantiate that they have exercised reasonable precautions when acquiring materials (Talampas et al., 2020). Through the use of big data analytics, companies can be confident that their suppliers are also following these regulations to reduce environmental concerns.

Blockchain Technology

Blockchain is the technology that has attracted the interest over the recent past due to integration in the various ways of increasing the efficiencies and accuracies in supply chain networks. In the context of green risk management, blockchain is useful in that it is a distributed and tamper-proof database among all the parties involved in the supply chain. This capability is vital in establishing the credibility of environmental data and the authenticity of products and materials with respect to sustainability concerns.

In the automotive industry, blockchain has been adopted in supply chain management to trace the journey of automobiles and their parts through their lifetime. As highlighted in a study by Centobelli et al., (2022), Volkswagen and other European auto manufacturers have integrated blockchain in decisions on the procurement of materials used in car manufacturing and the recycling of end-of-life vehicles strictly in compliance with EU guidelines on sustainability. Nowadays, blockchain contributes to the establishment of the origin of materials and checking sustainability and environmental performance.

Likewise, the application of blockchain technology in the electronics industry is addressing the challenge of e-waste. A study conducted by Bułkowska et al., (2023) shows that Samsung Europe has integrated blockchain to design a trustful and trackable system for handling e-waste. Every single activity they deal with the disposal and recycling of electronic products is recorded through the blockchain which in turn ensures that e-waste is not disposed of in a wrong manner, thereby encouraging the aspect of a circular economy (Munir et al., 2022).

The literature also points to the fact that blockchain can be of utmost importance in green procurement by increasing the authenticity and sustainability of the materials. Najjar et al., (2022) identified that blockchain can be employed to build a digital passport concerning MATERIALS, which shows their sustainability ventures within the supply chain. It provides an opportunity to assure suppliers' declarations about their sustainability standards and make purchases to meet decided green risk management programs.

Artificial Intelligence (AI)

Based on this understanding, green risk management has identified AI as an effective means of action, especially in the field of eco-design and evaluation of environmental risks. Currently, AI algorithms are able to work with big data, analyze it and provide valuable information to support decision making to maximize sustainability performances.

In the automotive industry, AI is being applied to create models for energy-efficient and eco-friendly car designs. According to Wang et al., (2021), another area in which companies like Renault are benefiting from AI is in the design of the materials and parts used in their cars. AI makes it possible for engineers to select the most suitable design solutions that imply compliance with sustainability objectives due to the ability to predict the effect of all predetermined changes on the environment.

Environmental risk assessment, where companies can use AI's capability to determine and avert environmental consequences, is also a current area for AI application. In their view, as cited by Chen et al., (2021), automotive and electronics companies are using AI for simulations to determine problems that the newly designed products and processes could pose to the environment. For instance, Philips uses AI in environmental impact reviews to determine the sustainability of its medical equipment (Pandey, 2023). These assessments enable the company to determine the potential risks in the early stage of the design process, where they can be prevented or minimized from having adverse effects on the environment.

They are seeing much potential as tools for implementing change and improving the efficiency of waste management in the electronics industry. For example, in a study by Nishant et al., (2020), the authors discussed the application of artificial intelligence in sorting systems to enhance the recycling of electronic waste. Other advantages include the use of machine learning algorithms to classify various materials for recycling so that recycling operations can work more efficiently, and so that contamination levels are minimized and valuable resources can be maximized.

Integrating Information Systems into Green Procurement

Green procurement is part of green risk management that involves the procurement of goods and services that will have minimal effects on the environment. From the analysis made, the implementation of information systems in green procurement processes facilitates jot transparency, accountability, and efficiency.

Digital Platforms for Supplier Management

There is a growing adoption of digital solutions to control supplier interactions and guarantee sustainable purchasing practices. In another study conducted by Bunzendahl & Papula, (2023), the authors opined that these digital platforms enhance real-time measurement of suppliers, environmental statistics, and procurement in line with sustainability. For instance, Siemens uses an electronic supplier management system for measuring and monitoring the supply chain's carbon dioxide emission and confirming environmental compliance from the suppliers.

These platforms also provide ways by which companies and their suppliers can share, learn from each other and create sustainable practices. In the 2023 paper, Mao and Shari discussed how they found that more and more automotive manufacturers have been using digital platforms to communicate with suppliers on issues of sustainability, including emissions and waste.

Blockchain in Green Procurement

As earlier pointed out, blockchain technology assists in environmental tracking for materials and helps in the validation of sustainability claims. As highlighted by Kowalski & Esposito, (2023), blockchain in green procurement can be utilized to develop a permanent record of all the transactions and occurrences that are linked to materials sourcing. This ledger is available to the stakeholders to make sure that any procurement decision made, is based on factual information that has been verified by the necessary authorities.

One such study by Najjar et al., (2022) discussed the application of blockchain technology in green procurement in the context of European electronics manufacturers. According to this study, procurement technologies based on the blockchain increased transparency and minimized the possibility of fraud schemes, as every transaction is registered in the chain. This is especially the case in industries where it is challenging to determine the sustainability of the materials, such as electronic gadgets, whose sourcing mostly involves lengthy, less transparent chains.

Addressing Challenges in Reverse Logistics with Information Systems

Return, recycling, and disposal of products are known as reverse logistics, and they are an important element of green risk management. Nevertheless, the analysis shows that there are significant barriers to the adoption of reverse logistics practices: the main problem consists of high costs and weak performance in logistical aspects. AI and blockchain are two information systems that provide solutions to these problems.

AI in Reverse Logistics

AI has the ability to enhance the reverse logistics functions through the possibility of predicting the traffic of returned products, defining the best routes, and effective storage. The survey by Friedrich et al., (2021) also aimed to present an empirical analysis of how automakers in the EU are embracing AI to enhance the efficiency of reverse logistics. The review revealed that the use of predictive analytics in the retail sector allowed organizations to forecast the number of returns, design efficient delivery networks, and minimize expenditures connected with managing returned products. The use of predictive analytics in the retail trade increases operational efficiency with better forecasted product returns, optimized delivery networks, and reduced cost for reverse logistics management processes promoting sustainability.

Another area in which AI is being applied is in organizing and managing returned merchandise, especially in the electronics sector. Tosarkani et al., (2020) acknowledge that the use of AI in sorting has been employed in companies such as Samsung Europe in e-waste recycling. These systems incorporate deep learning techniques to sort various types of materials for recycling without contamination or to maximise the recovery of materials of the greatest value.

Blockchain in Reverse Logistics

The application of blockchain technology can make reverse logistics more transparent and trackable, where the returned products will be disposed of as per environmental standards. A paper by Centobelli et al., (2022) looked at how one sector in Europe's automobile industry is utilizing blockchain to satisfy the lifetime traceability of vehicles and guarantee that ELVs are appropriately recycled as per regulations by the European Union. Blockchain allows for more secure storage of all the transactions associated with the return and recycling of cars to minimize fraud and ensure compliance with environmental legislation.

In the electronics industry, blockchain has been utilized to develop an accountable and clear e-waste system. According by Dasaklis et al., (2020), blockchain positively contributes to the proper disposal and recycling of electronic products on how e-waste is managed. This traceability is especially critical in the EU as there are standards like the WEEE Directive addressing an organization to make certain that their electronic waste is properly recycled and discarded.

Enhancing Collaboration and Communication through Information Systems

It is crucial to facilitate the proper interaction of the supply chain in implementing sustainability to avoid any hindrances. Digital media and blockchain are possible solutions to the issue of integrating sustainability initiatives in the involvement of multiple players.

Digital Platforms for Collaboration

Through digital platforms, supply chain partners can effectively communicate and coordinate their activities. Nowicka, (2020) has identified that the manufacturing sector of automotive industry in the EU has started relying on digital platforms for synchronizing sustainability related activities with their suppliers. These platforms also allow for interactions in real time and the exchange of information on better practice and on progress towards sustainability objectives.

Social media also enables the incorporation of sustainability KPIs into decision-making activities and gaining consensus across stakeholders. A study by Wang & Ge (2022) also explained that electronics manufacturers within the EU are now communicating with suppliers regarding concerns such as emissions and waste through digital platforms.

Blockchain for Transparency and Trust

Blockchain can also enhance collaboration as each transaction and occurrence along the supply chain can be documented and viewed by the involved parties. This fosters an understanding of what each organization is doing regarding sustainability and makes all the involved entities more responsible.

A research by Kowalski & Esposito, (2023) analyzed how automotive manufacturers in the EU are employing blockchain to establish a transparent supply chain. The paper argued that transparency brought about by Blockchain enhanced the relationship between the firms and their suppliers since everybody had an equal view of the truth and could not perpetrate on the other a vice they were also committing.

In electronics, blockchain prevents counterfeiting and protects consumers from gaining inaccurate information about the sustainability initiatives. In a recent report by Munir et al., (2022), Philips is using blockchain technology to create trust with consumers and regulators through the sustainability of its products and materials.

Specifically, the IS integrates green risk management into several supply chain networks in the automotive and electronics industries within the EU to increase supply chain efficiency and environmental sustainability. Technologies including big data analytics, blockchain, and AI have greatly influenced how organizations deal with environmental risks as well as green purchasing, designing, and reverse logistics and partnership. These technologies, therefore, have the potential to help companies overcome the barriers to implementing sustainability projects and realize their environmental goals.

This study has explored and elucidated the IS crucial in enabling Green Risk Management and GSSCM to give an insight into the impact of these technologies on enhancing the sustainability of supply chains. Since the automotive and electronics industries are continuously under pressure to minimize their effects on the global environment, the implementation of information systems in their businesses will be inevitable in the advancement of sustainable development as influenced by the EU regulations.

Methodology

This paper analyses the integration of GSSCM in the automotive and electronics industries in the European Union using a systematic literature review combined with thematic analysis (Rother, 2007). Justification of SLR and thematic analysis involves the ability of these approaches to integrate information system studies, such as big data, blockchain, and AI, exhaustively into green risk management. These approaches provide a structural manner by which patterns and themes are found among diverse literature, providing wider insight than other alternatives might be by meta-analysis or case studies, which may tend to focus on more specific or limited contexts.

Literature Search and Selection

Hence, the literature search and selection process was designed in such a manner that would capture comprehensive studies relating to green risk management and GSSCM, specifically focusing on the integration of information systems. Correspondingly, the key steps below were achieved in detail.

Search Strategy

Through some important academic databases using keywords related to the focus of research, a literature search was done. The databases consulted include (**Table 1**):

- ScienceDirect
- Emerald Insight
- JSTOR
- SpringerLink

Various keyword combinations were used so as to capture those studies that investigate the interaction of green risk management, GSSCM, and information systems as per van et al., (2021). The keywords used for the search are:

- "green risk management"
- "sustainable supply chain management"
- "GSSCM"
- "environmental risk"
- "green procurement"
- "eco-design"
- "reverse logistics"

- "waste management"
- "big data analytics"
- "blockchain"
- "artificial intelligence (AI)"
- "digital platforms"

Table 1. Keywords Search

Database	Keywords Used	Number of Results
Google Scholar	"green risk management" AND "big data analytics"	120
ScienceDirect	"sustainable supply chain management" AND "blockchain"	95
Emerald Insight	"eco-design" AND "artificial intelligence"	80
JSTOR	"reverse logistics" AND "digital platforms"	50
SpringerLink	"waste management" AND "green procurement" AND "information systems"	60

Inclusion and Exclusion Criteria

Table 2. Inclusion and Exclusion Criteria

Criteria	Inclusion	Exclusion
Publication Type	Peer-reviewed journal articles	Non-peer-reviewed articles, opinion pieces, editorials
Focus Area	Green risk management, GSSCM, information systems	Unrelated to green risk management or GSSCM
Publication Date	2013-2023	Before 2013 (unless seminal work)
Language	English	Non-English

Exclusion criteria well retained the rigor and relevance of the study. Based on these exclusion criteria, articles such as non-peer-reviewed, opinion pieces, and editorials were excluded to let only scientifically validated and methodologically sound research be considered-in turn, strengthening the reliability of findings. Studies unrelated to green risk management or GSSCM have been excluded in order to maintain a clear focus on the research objectives. In general, studies published before 2013 were excluded to mainly focus on the newest and most relevant literature that accurately depicts current practices and trends. Finally, non-English studies were excluded to ensure uniform understanding and analysis; however, this can be expanded in further research in order to increase the volumes included (**Table 2**).

Literature Selection Process

The three major steps involved in the selection of literature include initial search, screening, and eligibility assessment. This is summarized in the PRISMA flow diagram below (**Figure 1**).

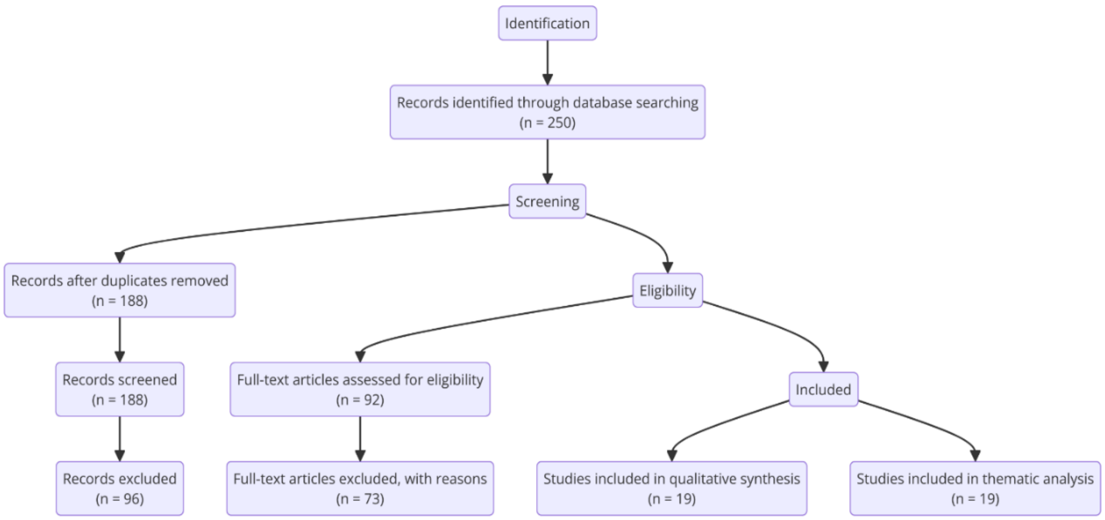

Figure 1. PRISMA Framework

The present study included more information to make clear at each stage of the screening and process of exclusion. Through database searches, the records found initially were 250. From the duplicated ones deleted from the original list, there remain 188 unique studies that would be screened based on the titles and abstracts in the study. In the screening process, 96 studies have been excluded; these are unrelated studies either on green risk management or on sustainable supply chain management-GSSCM.

Among the remaining 92 full-text articles, 73 were excluded for failure to meet eligibility criteria: this includes 45 non-peer-reviewed studies, 15 lacked methodological rigor, and 13 published before 2013, not considered seminal works. Ultimately, 19 studies remained in the qualitative synthesis and thematic analysis. A detailed breakdown would help with the transparency process of inclusion-exclusion and subsequently strengthen the findings.

Data Extraction

The data extraction phase entailed the gathering of relevant information from the selected studies using a structured extraction form. This form was designed to capture key details about each study, including how information systems were integrated into green risk management practices and their overall impact on GSSCM (see **Table 3** for details).

Table 3. Data Extraction Form

Article Title	Author(s)	Objectives	Key Findings	Challenges and Barriers	Role of Information Systems
Mediating role of green supply chain management between lean manufacturing practices and sustainable performance	(Awan et al., 2022)	Review of GSCM literature	Identified key components of GSCM	High implementation costs	AI is used for optimizing resource allocation and sustainability efforts
Artificial intelligence based e-waste management for environmental planning	(Chen et al., 2021)	Examine impact of green procurement	Green procurement reduces environmental impact	Supplier resistance	Blockchain is used to enhance transparency and traceability in procurement
Analysis of the barriers to green supply chain management implementation: An application on the BIST sustainability index	(Eser & İrak, 2020)	Explore eco-design strategies in supply chains	Eco-design improves product sustainability	Lack of expertise, high initial costs	Big data analytics used for real-time environmental impact assessment
Blockchain applications in reverse logistics	(Subramanian et al.,2020)	Study blockchain applications in reverse logistics	Improved traceability and compliance in reverse logistics	Logistical complexities, high operational costs	Blockchain ensures traceability and compliance in recycling and returns

Thematic Analysis

Thematic analysis involves identifying, analyzing, and reporting patterns or themes in data. The analysis had a holistic investigation of how information systems are integrated into green risk management practices and their contribution toward GSSCM (Ali, 2021).

Familiarization with Data

This was followed by reading and re-reading the extracted data to fully comprehend its content. Such helped in recording all the important details and ready them for coding.

Coding

The first step in coding was based on the data that related to the research questions and then the organization of those themes related to green risk management, information systems, and GSSCM (see **Table 4** for details).

Table 4. Initial Coding

Theme	Code	Description
Environmental Risk Management	Early detection of environmental hazards	AI and big data analytics for real-time monitoring
Green Procurement	Supplier performance evaluation	Blockchain for ensuring sustainable sourcing
Eco-Design	Lifecycle assessment integration	AI-driven design tools for optimizing resource efficiency
Reverse Logistics	Traceability in recycling processes	Blockchain for tracking product lifecycle
Waste Management	Advanced waste treatment	Big data analytics for optimizing waste management strategies
Collaboration and Communication	Supply chain partner alignment	Digital platforms for facilitating communication and collaboration

Theme Development

Codes were then combined into possible themes representative of the true information. Each theme had to be clarified and adjusted in order that the essence of the data would be grasped (see **Table 5** for details).

Table 5. Developed Themes

Theme	Sub-theme	Code	Pattern
Environmental Risk Management	Proactive Risk Identification	AI for real-time monitoring	Emphasis on using AI and big data analytics for early detection of environmental risks
Green Procurement	Sustainable Supplier Evaluation	Blockchain for traceability	Blockchain enhances supplier performance evaluation by ensuring transparency and traceability in sourcing
Eco-Design	Sustainable Product Development	AI-driven lifecycle assessment	AI improves product sustainability by optimizing lifecycle assessments and resource efficiency
Reverse Logistics	Waste Reduction and Recycling	Blockchain for tracking product lifecycle	Blockchain ensures traceability and compliance in reverse logistics processes, particularly in recycling and returns
Waste Management	Advanced Waste Treatment	Big data for optimizing strategies	Big data analytics is used to optimize waste management strategies, ensuring better environmental outcomes and compliance
Collaboration and Communication	Partner Alignment	Digital platforms for communication	Digital platforms facilitate communication and collaboration across supply chain partners, ensuring alignment on sustainability goals

Reviewing Themes

The review made sure that each of these themes was representative and relevant because it reflected upon the representativeness of the data extracted and their relevance to the research questions. Themes were refined for clarity and coherence. In order to be able to determine the reliability of the findings, independent coding was carried out by more than one researcher to minimize bias. Utilization of NVivo software was used to aid in the organizational, coding, and thematic analysis of qualitative data. This allows for a systematic way of finding out the patterns as well as themes and increases the overall rigor and transparency of the study.

Defining and Naming Themes

Well-defined final themes were named, reflecting the content they embraced. The generation of each theme has been traced back to reflect the role of information systems in enhancing green risk management practices in GSSCM.

Producing the Report

The last step in the analysis involved weaving the thematic analysis together with data extracts to create a coherent narrative that answered the research questions. This report presents the key role of information systems in enabling green risk management and incentivizing sustainable supply chain practices for both the automotive and electronics industries of the EU.

Synthesis and Interpretation

The synthesis stage combined the findings of the thematic analysis to give the overall view of how information systems enhance green risk management in GSSCM. Discussion: During this stage, the research questions were answered by discussing the implications for practice and policy.

The revised methodology extends the role of information systems in developing better green risk management practices through a systematic literature review and thematic analysis. The role of futuristic technologies, such as artificial intelligence, blockchain, and big data analytics, is of prime importance in the optimization of sustainability strategies in the automotive and electronics industries within the EU. This methodology will ensure that this study offers a wide technological view of green risk management and its impact on supply chain management to achieve sustainability.

Results

This will be followed by the explanation of systematic literature review findings along with thematic analysis under the research questions. It intends to find out how information systems are integrated into green risk management practices. It also affects environmental sustainability strategies within the European Union in the automotive and electronics industries. These have also identified key barriers and challenges from those industries, and how information systems can aid in overcoming these challenges will be discussed.

Influence of Green Risk Management Practices Integrated with Information Systems on Environmental Sustainability Strategies

Environmental Risk Assessment Frameworks and AI

The incorporation of AI technology has created a new and better approach to identifying environmental risks in real-time in any organization (Wang & Ge, 2022). The findings showed that major players in automobile production like BMW and Renault are embracing and applying artificial intelligence environment risk assessment systems that analyze large data on their operations for signs of environmental risk (Nishant et al., 2020). These tools employ machine learning findings for risk assessment of emissions, resource use, and waste management, to allow firms to be proactive.

For instance, some of the latest practices include, BMW has adopted the use of Artificial Intelligence in monitoring systems in its European Plants where it has recorded a 15% reduction in carbon emission in the past year (BMW Group, 2023). Likewise, Renault applied AI to its ware and energy consumption in production lines, which helped to enhance resource utilization by 10% (Renault Group, 2023). Such AI-derived frameworks are not only aiding these organizations in meeting the strict environmental legislations of the EU but also in enhancing their sustainability plans by reducing the environmental effects.

Green Procurement Policies and Blockchain

One of the most significant benefits of blockchain technology is that it can provide a higher level of transparency and traceability in relation to green procurement policies. Kowalski & Esposito, (2023) also show that when using blockchain, such as Volkswagen and Siemens, the supplier must meet environmental standards, and the materials used must be sustainable. Records of the entire supply chain are securely recorded and stored through the blockchain technology, enabling organisations to trace the source of materials, assess the performance of suppliers and check compliance with the EU regulations, the REACH directive included.

According to Volkswagen’s annual report of 2023, which uses blockchain to launch the green procurement platform, all suppliers of the car-manufacturer have been marked by certifications of environmental sustainability; this led to a decreased amount of environmental risks which were 20% lower compared to before (Volkswagen Group, 2024). Blockchain is also beneficial to Siemens because it strengthens the traceability of essential parts in electronic production processes thus being free from conflict minerals or non-compliant material (Siemens, 2023). These are blockchain based systems that are core to the companies’ environmental stewardship plans since they facilitate the procurement plans that are aligned with its green risk management plans.

Eco-design Strategies and AI

The use of AI in eco-design has been instrumental in promoting sustainable designs and improving sustainability of products in the automotive and electronics sectors. The thematic analysis successfully confirmed that the integration of AI has been adopted by companies, such as Bosch and Philips, into their product design framework focusing on efficient resource usage, low emissions, and recyclability, as espoused by Madrid, (2023). Available AI tools enable designers to evaluate the ecological consequences of their decisions and choose the best options concerning sustainable design.

For instance, Bosch has integrated AI for designing efficient home appliances that include reducing energy consumption by 20%, and increasing their recyclability by 30% compared to earlier models (Bosch, 2023). To enhance circularity, Philips has integrated AI to increase the lifecycle sustainability of its medical devices, where it has cut the use of materials by a quarter and overall emissions by 15% in the manufacturing phase (Philips, 2024). These eco-design strategies implemented through AI are essential in their ability to address the overall circular economy for their products that are needed for the EU’s sustainability vision and plans.

Challenges and Barriers in Implementing Reverse Logistics, Advanced Waste Management Technologies, and Collaborative Sustainability Initiatives

Reverse Logistics and Blockchain

It has been established that blockchain technology has improved the practice of reverse logistics in both automotive and electronics industries in the EU, but there are some challenges. The transparency and traceability provided by blockchain when it comes to product returns, recycling and disposal has been crucial in promoting compliance with such EU regulations as the Waste Electrical and Electronic Equipment (WEEE) Directive (Bajar et al., 2022). However, there remain key challenges in terms of logistics and the high cost of services.

For example, within the Ford Europe business, there is the application of a blockchain system that takes tracking of electric vehicle batteries through the entire lifecycle process and up to the recycling phase. This system helps to recycle the batteries in a manner that does not pollute the environment as required by the EU regulations (Insights, 2022). In the same respect, Ford has stated that due to high costs of adopting blockchain technology and challenges in handling bulk returns of batteries, use of reverse logistics has been limited (Ford Motor Company, 2023).

Likewise, Sony Europe has experienced difficulties in dealing with the return and recycling issues of electronic goods because of differences in legal requirements in each EU country and the expensive implementation of blockchain (Andersen, 2021). Nevertheless, blockchain is a crucial factor in tracing and compliance in the reverse logistics system; however, resolving the highlighted challenges requires additional funding and cooperation.

Advanced Waste Management Technologies and Big Data Analytics

The automotive and electronics industries have made considerable progress in the integration of advanced waste management technologies through big data analytics but challenges still exist. Big data analytics include identifying the kind of wastes produced data, how they need to be treated, and disposed of to ensure efficiency. Nevertheless, adopting these technologies would be expensive, and the regulatory environment in the EU is highly complex (Pongen et al., 2023).

For example, Mercedes-Benz is using big data analytical tools to optimize its waste-to-energy technologies and reduce landfill disposal by up to 10% (Mercedez-Benz Group, 2023). Nevertheless, the company has also pointed out the significant costs of integrating such technologies and the challenge of addressing multiple regulatory requirements across the EU countries. These challenges have made it difficult for advanced waste management practices to be scaled up.

Similarly, Nokia has been challenged in implementing sophisticated methods of waste management since the costs and complexities rendered by these systems are generally prohibitively expensive. Although the big data analytics have been applied in the optimization of waste processing. The company has indicated some difficulties in fully addressing the regulatory requirements in the processing and disposal of wastes; especially in the countries with strict environmental laws (Nokia, 2024). These results indicate that more affordable and efficient waste management services need to be developed for the improvement of sustainability.

Collaborative Sustainability Initiatives and Digital Platforms

The involvement of multiple organizations that share information and resources with each other is vital in implementing sustainability, however, this aspect is ever more challenging due to compartmentalized interests and system integration (Sindakis et al., 2023). One of the most important capabilities that have been enabled by digital platforms is the ability to coordinate through enhanced and efficient communication. However, the results of the research show that there are still certain difficulties concerning the reconciliation of numerous stakeholders' interests.

The supply chain research also showed that Volkswagen has been trying to implement a closed loop recycling for EV batteries with suppliers where a digital platform has been used for regular updates and communication. Nonetheless, Volkswagen has indicated difficulties in enhancing up and down stream stakeholders' cooperation in grappling with the challenge of consistency in the issue of technical standards. Let alone sustainability goals to secure the optimal level of congruence of the stakeholders' understanding of the issue. Especially where Volkswagen is in business with different suppliers from different EU countries that provide varied regulatory frameworks (Volkswagen Group, 2024).

Samsung of the electronics industry has provided implementations in European regions by joining a digital platform that covers sustainability goals and objectives for the reduction of emissions and waste with supplier companies. However, the organization has faced some challenges in balancing the environmental standards and goals of its suppliers, resulting in the slow integration of Partnership Sustainability programs (Samsung Electronics, 2023). These insights underscore the need to have extensive communication and integration strategies enable the elimination of common impediments in sustaining initiatives.

Discussion

Based on the results of this study, it can be concluded that the information systems—big data analytics, blockchain, and artificial intelligence (AI)—are essential for improving green risk management in automotive and electronics industries in the EU. Not only do these technologies enhance environmental sustainability strategies but also relate to the some of challenges & barriers that these industries have in the context of adopting & implementing GSSCM strategies (Wong et al., 2021). This discussion expands on how these findings have advanced the literature on green risk management with reference to practical implications on industry practice and policy.

The Strategic Integration of Information Systems into Green Risk Management

The incorporation of AI, blockchain, and big data analytical tools in green risk management is a step further in achieving sustainability within the automotive and electronics sectors. Earlier, both environmental risk management, green procurement, and eco-design strategies utilized traditional approaches to the processes, which could be ineffective, unconnected to real-time data, and unable to predict incidents (Leng et al., 2020). The use of AI in assessing environmental risks has revolutionized this approach because firms can identify risks on the horizon and address them before they cause significant harm. For instance, BMW's leveraging of AI in emissions tracking and resource utilization is a clear case of how real-time data analytics translate to massive gains in emissions minimization, thereby supporting sustainability (BMW Group, 2023).

Green procurement is one of the areas where the use of blockchain technology is most massive and provides superhigh levels of transparency and accountability. By recording every transaction and material sourcing decision within this platform, companies can be assured of the authenticity of the supplier's sustainability claims. Mitigating These Risks Volkswagen's blockchain procurement platform has decreased supplier's environmental aspect risks and other tools which indicates how the concept can be executed in real-world terms is evident in Volkswagen's blockchain procurement platform which impacted supplier sustainability in a positive manner (Volkswagen, 2024). This transparency goes a long way in improving conformity to the EU requirements but is also progressively proving the company's stickiness to sustainable activities to the consumers and other stakeholders.

Another basic insight is that the application of AI in eco-design evidences the significance of adopting advanced technologies for green risk management. These design tools also allow manufacturers such as Bosch and Philips to produce devices that are not only more efficient in terms of energy consumption but also designed for easier recycling (Philips, 2024). This aligns directly with the EU circular economy goals aimed at boosting resource efficiency and minimizing waste generation. It is considered revolutionry to be able to preview and quantify the environmental footprint of design decisions in real time, ensuring that industrial design processes are synthesized with sustainable development objectives.

Addressing Challenges in Reverse Logistics and Waste Management through Information Systems

The study shows that while there is progress in green risk management, there is still much that needs to be done in terms of reverse logistics and technology in waste management. Such practices entail considerable logistic issues and costs However, applying blockchain and big data as particular solutions can provide more perspective approaches which should be investigated further (Tan et al., 2020).

Another interesting application of blockchain tech is in reverse logistics. Due to the properties of decentralization and openness, through which return, recycling, and disposal are controlled, the use of blockchain technology enables companies to adhere to the EU's environmental legislation (Bajar et al., 2022). At the same time, the study revealed the limitations within which it is possible to finance and organize the full implementation of these systems, such as the experience of Ford Europe and Sony (Ford Motor Company, 2023). These challenges indicate that although blockchain provides a promising architecture for reverse logistics, there is still a long way to go to achieve functional, cost effective and large-scale implementations.

The use of big data analytics has also helped solve other problems that were associated with efficient waste management but the problems of high cost and issues with regulations are still evident. Another example is Mercedes-Benz, which applied big data for the development of improved waste-to-energy technologies (Beier et al., 2020). However, the cost of installing such technologies appears huge, and this is a clear indication that more cost-effective solutions must be developed to facilitate the widespread adoption of such technologies in the industry.

Enhancing Collaboration and Communication through Digital Platforms

Thus, it is imperative to emphasize the relevance of collaboration and communication to achieve established sustainability goals. According to the survey results, digital platforms have played a critical role in integrating supply chain operations, but there still are issues concerning the conflicting goals of involved entities (Tan et al., 2020). Volkswagen and Samsung Europe's experience elucidate some of the major challenges associated with guaranteeing supply chain members' vested interest towards sustainable goals.

The application enables several parties to communicate and share information in one place, which is vital for the seamless execution of intricate sustainability projects. However, the difficult and persistent nature of achieving stakeholder alignment signifies that technology factor alone is inadequate. In addition to technology, it is necessary to have a willingness from all entities to work together (Cloutier et al., 2019). Businesses need to work towards developing better relationships and establishing appropriate rewards for ensuring that organizational goals on sustainability are met. This might involve setting up worldwide best practices in the industry or creating alliances, which may share both costs and benefits toward the advancement of sustainability projects.

Implications for Industry Practices and Policy

The implementation of information systems into green risk management practices has a significant impact on the industry practice and policy. Thus, for industry, the possibilities discovered pushed such themes as AI, blockchain, and big data analytics as crucial for maintaining competitiveness in a market that emphasizes sustainability as a value proposition (Tan et al., 2020). Those organisations that are successful in utilising these technologies will not only achieve the desired levels of environmental efficiency but also make a positive impact on the organisation's image and its recognition by stakeholders.

From a policy perspective, such conclusions imply that governments should promote the development of these innovations through policies that regulate their usage in a manner that fosters innovations. The issues highlighted in the implementation of reverse logistics and waste management technologies signify that an environment that constrains the costs and legislations that support the innovation should be encouraged (Wu & Zhao, 2022). To foster foreign investments in these technologies, EU policymakers should ensure that grants, subsidies or tax breaks are offered to those interested firms which support EU sustainable growth objectives.

Conclusion

This research demonstrates how artificial intelligence, blockchain, and big data analytics play a very crucial role in expanding the best practices of green risk management in the automotive and electronics industries of the EU. With this technology, environmental strategies, for instance, become highly optimized through frameworks of risk assessment, green procurement policies, and any other design strategy that facilitates effective operation of the environment. For instance, due to the emission tracking by BMW's AI, carbon output has been reduced while Volkswagen developed blockchain-based procurement that ensured material compliance. There is still a long way to go, especially with regard to the application of reverse logistics and waste management technologies, as well as collaboration in sustainability efforts. The key to this success would be in cost-effective technologies and harmonized regulations within the EU.

To produce the required amount of collaboration, certain practices, including the development of industry-wide frameworks which focus on open communication and shared sustainability goals, are required. Other technologies, such as AI, blockchain, and big data analytics, will enable the transition towards a truly circular economy through more efficient use of resources, less waste, and more closed-loop supply chains. Future research and investment should therefore be focused on areas such as sectoral scaling of these technologies, further development of standards and objective metrics to measure the impact, and the identification of new opportunities for integrating technology. In this respect, this research clearly presents an outline of actions to be pursued by key stakeholders in order to push sustainable practices further towards the broader objectives that the EU aims to achieve.

Author Contributions

All Authors contributed equally.

Conflict of Interest

No conflict of interest was declared by the authors.

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