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Sustainable Synergy: How AI Transforms Supply Chains into Green Supply Chains

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ABSTRACT

Purpose: The article aims to investigate the strategic use of convergence between Artificial Intelligence (AI) and Supply Chain Management (SCM) by businesses to promote sustainability throughout the supply chain. Its emphasis AI's capacity to tackle triple-bottom-line concerns – resource efficiency, environmental stewardship, and social responsibility- by streamlining operations, minimising carbon footprints and promoting "green" activities within supply networks. The goal is to give companies a complete guidance on how to use AI-powered technologies to improve sustainability and operational performance, which will make their supply chain stronger and better for the environment.

Design/Methodology/Approach: The study utilises a conceptual framework to systematically review existing literature, creating insights from various array of recent journal publications, with a particular focus on those examining the application of AI in the supply chain processes through the lens of Environmental Social and Governance criteria (ESG). The study consists of qualitative and quantitative assessments and utilises pertinent case studies to show optimal practices in the application of AI for sustainable supply chain management.

Findings: The review reveals that AI technologies help make supply chains more sustainable by allowing real-time tracking, predictive analytics, an automated decision-making. AI-powered solutions make productions, inventory, transportation, and logistics more efficient. This cuts down on pollution, waste, and resource utilisation. Examples from companies show that top enterprises that use AI see improvements in operational efficiency and environmental sustainability. They benefit from better process transparency and more flexible resource allocation.

Originality / Value: This study gives a complete and in-depth view a how AI might help supply chains be more environmentally friendly and socially responsible. It also gives useful advice for both researchers and people who work in the field. Its distinctive value resides in its comprehensive and current literature synthesis, thorough analysis of ESG catalysts technological barriers, and incorporation of case-base insights.

Paper Type: Theme Based Paper

KEYWORDS: AI | Sustainability | Supply Chain Management (SCM) | Triple Bottom Line | Green Supply Chain Management (GSCM), Green AI

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Introduction

In today's landscape of climate change and a surge in environmental awareness, companies are delightfully advancing to infuse sustainable practices into each dimension of their operations—especially in their supply chains. The captivating integration of Artificial Intelligence (AI) and Supply Chain Management (SCM) denotes a splendid change in the approach organizations take towards sustainability. With growing enthusiasm to lessen carbon footprints and embrace greener practices, AI is becoming a wonderful ally in fostering environmental and operational advancements throughout supply chains.

A supply chain is the path that raw materials, partly made goods, and finished products take from suppliers to the final customers. In the past, managing these supply chain activities has needed a lot of resources, often leading to high energy use, large amounts of greenhouse gas emissions, and other harmful effects on the environment.

Today, making supply chains more eco-friendly is not just a good idea—it's also important for staying ahead in business. There are many ways to use modern technology to make this happen. By studying large amounts of information and using smart tools, companies can find problems, use resources more wisely, reduce waste, and cut pollution. This can make supply chains not only better for the environment but also cheaper to run, quicker to respond to changes, and more flexible in meeting customer needs.

Sustainable AI is about lot more than just lowering carbon footprints or achieving environmental goals. It's also about ethics, fairness, and social responsibility—making sure that AI is made in a way that is responsible, respects people's privacy, is open about how it works, and treats everyone fairly. This holistic picture fits well with the United Nations' Sustainable Development Goals (SDGs), which aim not only avoid harm but also make lasting improvements for businesses, communities, and the planet.

Similarly, Green Supply Chain Management (GSCM) redefines traditional supply chain practices and makes them more sustainable. As Ali et al. (2019) says that GCSM is about cutting down on waste, using energy wisely, buying things that are good for the environment, and keeping track of how well you are doing in terms of sustainability. It's also about building supply networks that can bend without breaking—able to adapt when the unexpected happens—so they keep running while still honouring their commitment to the planet.

AI can enhance demand forecasting by analysing vast amounts of data, including historical sales data, market trends, consumer behaviour patterns, and external factors such as weather and economic indicators. The transition toward more sustainable transportation modes, such as electric vehicles (EVs) or intermodal transportation (combining multiple modes like rail, truck, and ship) can be facilitated through AI. It can optimize warehouse layout and material handling processes to improve energy efficiency and reduce waste. By using computer vision and robotics, warehouses can handle tasks more smoothly, lower the strain on workers, cut costs, and avoid mistakes that often lead to unnecessary waste.

By looking at sensor readings, past repair records, and weather or working conditions, companies can predict when a machine might break down or need fixing. They can also choose the best suppliers by checking things like how eco-friendly they are, how they handle waste, whether they have environmental certificates, and how much pollution they cause. These practices can make the supply chain work more smoothly, save money, and increase profits. They also improve the company's reputation, help it stand out from competitors, and attract customers who care about the environment. On top of that, it reduces the chances of breaking strict environmental rules.

Review of literature

AI for greening the supply chain is the use of artificial intelligence (AI) to make supply chains more environmentally friendly. This involves creating and using smart systems that actively lower ecological footprints (Raman et al., 2024). This can make work run more smoothly but it also helps the environment by lowering carbon emissions, cutting down on waste, and encouraging people to save energy. Combining several strategic paradigms, such as lean, agile, resilient, and green supply chain approaches, can also help a supply chain and grow in changing business environments.

Carvalho and Cruz-Machado (2011) say that using the combination of these methods lets businesses make supply chains that are cheap and quick to respond to, as well as good for the environment and society. AI powered predictive maintenance can help machines last longer and use less energy. Machine learning algorithms can also help use resources more wisely and reduce waste (Russell & Norvig, 2020).

A review of the evolving landscape of AI sustainability, addressing economic, social, and environmental dimensions was done (Dhiman et al., 2024). Green brand strategies in the fashion industry include eco-labelling, competitiveness in the fashion supply chain network, and reverse logistics as a sustainable supply chain technique (Choi & Cheng, 2015).

A Survey from over 300 organizations in China confirm that the informal alignment between Green Supply Chain Management (GSCM) and Green Information System (GIS) enhances economic, operational, environmental and social performances (Yang et al., 2020).

Bottani & Murino (2021) performed a bibliometric analysis to find out the most common topics in green supply chain management (GSCM), find important themes, and point out that more research is needed in this area.

There are many reasons why it is so important to have sustainable supply chain operations:

Climate change and environmental degradation: The Intergovernmental Panel on Climate Change (IPCC) says that people have already made the earth about 1.1°C warmer than it was before the Industrial Revolution. If greenhouse gas emissions don't drop significantly, the planet will likely exceed the Paris Agreement's goal of keeping global warming to 1.5°C (IPCC, 2021). Supply chains add a lot to these emissions through transportation, energy use, and trash production.

Business practices that are good for environment: A 2021 survey by IBM found that about 60% of people are willing to change how they shop to have less of an impact on the environment. 78% of consumers also say that sustainability is essential to them when they buy things (IBM, 2021). If Companies don't deal with sustainability issues, they could lose market share and damaging their reputation.

Regulatory frameworks and government policies: The European Union has put the Green Deal into effect. This is a set of rules that will make Europe climate-neutral by 2050 (European Commission, 2019). These regulations motivate businesses to use environmentally friendly methods, including in how they handle their supply chains.

To get the most out of AI, companies that make AI need invest money on new technology, train their workers, and keep their data safe. AI-driven solutions can help businesses work better, save money, and boost their eco-friendly efforts (Seuring & Müller, 2008). Businesses need to make sure that AI technologies fit smoothly with their current infrastructure so that there are fewer problems and more benefits (Kleindorfer et al., 2005). To handle the challenges of using AI, companies should train their workers on how to use AI tools well, protect sensitive data from cyber threats by putting in place strong security measures a regularly updating systems, and make sure that AI systems work well with existing infrastructure to reduce disruptions and get the most out of them (Kleindorfer et al., 2005). McKinsey & Company, says that AI-powered supply chain optimization could save the world $1.3 to $2 trillion a year across in many fields (McKinsey, 2016). A survey by Cone Communications found that 88% of customers would stay more loyal to a company that supports social or environmental causes (Cone Comm, 2017). Toorajipour et al. (2021) reviewed AI use in supply chain management, and found several crucial areas where AI contributes to sustainability. Some of these are predicting demand, keeping track of inventory, and making transportation more efficient.

All of these can help cut down on waste and lessen carbon emissions. AI research has also looked at transportation which is a big source of emissions in the supply chain. Blockchain technology and AI working together have showed potential in making supply chains more open and traceable, which are important for efforts to make them more sustainable.

Application of Green AI in SCM

In the realm of supply chain management, AI offers a host of applications for greening supply chains:

Table 1: Application of Green AI in SCM

S No	Area	Description	Author
1	***Production Process Optimization***	The interdependence of various products of many firms are forcing technology companies to devise their strategies AI can streamline manufacturing processes, reducing energy consumption and material waste. After analysis of production data, AI systems can identify inefficiencies and recommend adjustments to enhance sustainability	Kozlovskyi et al. (2025); Chatterjee et al. (2025); Boršoš & Koman (2025); Canatan et al. (2025); Yu et al. (2025); Alghieth (2025);
2	***Supply Chain Logistics***	AI-powered routing algorithms can optimize delivery routes, minimize fuel consumption, and reduce emissions by taking into account traffic patterns, weather conditions, and other variables to create efficient delivery schedules	Bulková et al. (2025); Kostovčík et al. (2025); Miller et al. (2024); Suthagar & Mishra (2025); Chowlur Revanna & Al-Nakash (2024); Dikshit et al. (2023)

3	***Material Usage***	AI can help businesses choose materials that are good for the environment and cut down on waste. AI can find ways to replace harmful materials with eco-friendly ones and make sure that resources are used efficiently by looking at supply chain data.	Rodrigues et al. (2025); Waltersmann et al. (2021); Onyeaka et al. (2023); Khan Lodhi et al. (2024); Farshadfar et al. (2024);
4	***Enhancing Supply Chain Efficiency with AI***	Green AI makes supply chains work better by making transportation networks more efficient, using less fuel, and making fewer emissions. AI can keep an eye on and predict inventory levels, which means you don't need as much extra stock which is better for the environment.	Soomro et al. (2025); Wu & Zuo (2023); Liu (2023); Amado Mateus (2024); Miralam (2025); Salhab et al. (2025); Riad et al. (2024); Elmousalami et al. (2025)
5	***Optimizing Transport Networks***	AI-powered routing algorithms can find the best delivery routes, which helps cut down on fuel use and emissions. Transportation is responsible for about 24% of global CO_2 emissions from fuel combustion, which is a major source of greenhouse gas emissions in supply chains. Using AI to find the best routes for delivery vehicles could cut down on their emissions.	Agnes Clare Odimarha et al. (2024); A. Li et al. (2024); Fatorachian et al. (2025); Chen et al. (2024); Lin et al. (2022); Tsolaki et al. (2023); Thakur (2024); Prakash et al. (2024); Shi et al. (2025);
6	***Demand Forecasting and Production Planning***	Machine learning algorithms can find complicated patterns in data, which makes it possible to make more accurate predictions about demand than traditional statistical methods.	Riachy et al. (2025); Irhuma et al. (2025); Salais-Fierro & Martínez (2022); Yang et al. (2025); Rao et al. (2025)
7	***Inventory Management &Warehouse Optimization***	Machine learning algorithms can find accurate inventory levels, reorder points, and replenishment strategies to cut down stockouts	Namir et al. (2021); Pasupuleti et al. (2024); Tan et al. (2024); Preil & Krapp (2022); Albayrak Ünal et al. (2023); Qi et al. (2023)

8	***Predictive Maintenance and Asset Management***	Predictive maintenance in factories powered by AI less unplanned downtime and longer equipment life.	Ojha et al. (2025); Çinar et al. (2020); Schwendemann et al. (2021); Shokri et al. (2025); Qalbina et al. (2025); Rojas et al. (2025); Strielkowski et al. (2023); Peruničić et al. (2025); Vaidya & Jethava (2025)
9	***Supplier Selection and Collaboration***	AI can help suppliers work together and share information, which can lead to long lasting solutions.	Weisz et al. (2025); Andres B et al. (2023); Gazi et al. (2024); S. Li et al. (2021); Olan et al. (2022); Cavalcante et al. (2019); Wang & Zhang (2025); Sundaresan & Zhang (2022); Sun et al. (2025); Rezaei et al. (2024)

The table above shows some of the benefits of AI in Supply Chain Management. This shows that researchers predicted use of ICT in SCM pretty early.

Indicative Case studies

Several top firms have successfully implemented AI programs for greening their supply chains, realizing impressive results in operational performance and ecological sustainability. For example:

Amazon: An AI model called the Packaging Decision Engine helps choose the best possible packaging for products that customers can order. Since 2015, Amazon has removed more than two million tons of packing material globally. All fulfilment centres utilize AI-powered technology to identify damaged goods. Machine learning-based solutions are being used by the food teams at Amazon Fresh to automate fruit and vegetable shelf monitoring in stores. Amazon unveiled a number of AI-powered improvements that benefit customers by decreasing returns and improving environmentally friendly shopping. An AI-based technique called Flamingo was created by Amazon to determine an item's carbon footprint. By investing in AWS chips and upgrading our cloud infrastructure to be more energy-efficient, Amazon is also enhancing the sustainability of AI (Amazon, 2024)

Unilever: AI has been integrated into Unilever's supply chain to improve waste reduction and resource efficiency. Unilever R&D professionals have been utilizing digital technology to stay at the forefront of great innovation for years, starting with the introduction of the world's first digital tool and most recently with the creation of the first green carbon detergent. AI is used to recognize and forecast consumer trends before they materialize. "In-silico" product design uses computational models. Utilizing production simulations and R&D and supply chain data, items are optimally deployed to 3.4 billion daily consumers globally. AI is utilized to find substitute ingredients that can improve the supply chain's resilience and increase the sustainability and economy of formulations. In order to produce a single, distinctive aroma using AI, Axe A.I. Body Spray was developed with 46 terabytes of data, 6,000 components, and 3.5 million possible fragrance combinations (Unilever, 2024).

DHL: Sorting capacity in express logistics is being increased by up to 40% thanks to AI-driven sorting robots. DHL Bots can sort over 1,000 small packages per hour with 99% accuracy, reducing mis-sorting and obviating the need for secondary sorting. This technology is addressing the consistent rise in shipments across the region. According to DHL's Global Online Shopper Survey 2023, 64% of European customers value sustainable deliveries, and the company is thought to be the most ecologically conscious of

all the major international delivery services. An AI-driven packaging solution has been created by DHL to improve environmental sustainability and reduce shipping costs. "OptiCarton" is a smart system that helps pack more items into boxes. It uses advanced methods to figure out the best way to fit products and combines that with a flexible, on-demand packing process in the warehouse. (DHL, 2024).

Walmart: Walmart, the biggest retailer in the world, has been using smart technology like AI and machine learning to make its supply chain eco-friendlier and more efficient. With the help of AI, Walmart studies things like shopping habits, customer behaviour, seasonal trends, and popular products. This helps the company predict when demand will rise—especially during busy or unexpected times—and run its supply chain more smoothly. For many years, Walmart has relied on AI to cut down waste, reduce pollution, and make sure customers can easily find the products they love whenever and wherever they need them. The company has also shared its award-winning logistics system, called Route Optimization, with other businesses as a software service. By improving its routes, Walmart has saved 94 million pounds of carbon emissions, avoided 110,000 wasteful delivery paths, and cut out 30 million unnecessary miles. Because of this big achievement, Walmart received the well-known Franz Edelman Award in 2023 for successfully putting this strategy into action.

Siemens: Siemens is a big industrial company that works all over the world, and it has started using AI in its supply chain and other parts of its work. This shows how a big company can use new technology to solve problems and do well in a tough market. By using AI for forecasting, supply chain management, teamwork, and more, Siemens is setting an example for other companies. Its success with AI also shows that the future looks good, as it is leading the way in Industry 4.0 and digital transformation.

To avoid relying too much on a single supplier, Siemens uses tools like chatbots to find other suppliers and spot possible risks in its supply chain. The company also works with others, such as Supply frame, to understand and predict challenges, risks, and trends in the global electronics market. By linking real-time supply chain data to its Siemens Accelerator and digital twin systems, Siemens can manage the availability of parts more effectively and keep better track of costs.

In the industrial sector, green hydrogen is essential to reaching sustainability goals. Siemens, a technology corporation, plans to provide software solutions based on generative artificial intelligence to enterprises in the hydrogen industry to expedite the hydrogen ramp-up (Siemens,2024).

These examples show how AI solutions are being used by businesses in a wide range of fields such as e-commerce, logistics, consumer goods, retail, and technology, to improve their supply chain operations, cut down waste, use less energy, and have less of an effect on the environment.

Challenges and opportunities

Let us discuss the challenges and opportunities of employing AI in managing supply chains:

Challenges:

There can be several and complicated issues when applying artificial intelligence (AI) technology to supply chain management (SCM). In a global sense, AI is being used to support sustainability, but we should evaluate the experiences with AI technology to assess its benefits and risk (Dauvergne, 2020). The first barrier to AI implementation in SCM is the investment in infrastructure and technology, which can be costly. That infrastructure may also apply to the people needing to develop, manage and operate these systems, and the investment can be substantial. The second barrier may be data and the availability of quality data; these are critical issues for AI implementation. Supply chain management involves large and complex networks of manufacturers, suppliers, and distributors that are generating lots of data in the process. These supply chain partners may be reluctant to share the information that AI solutions require to improve a process, due to concerns also relating to privacy and security.

Opportunity

The use of artificial intelligence (AI) in supply chain management (SCM) provides many opportunities for companies that can yield improved sustainability and efficiency strategies. As companies continue to realize that environmentally sustainable practices are needed in the operations, AI can exist as a viable tool to assist with the initiatives for sustainable development by providing automation across the full ecosystem of the supply chain. The opportunities that AI affords companies include all aspects of supply chain management (SCM), from automating decision processes to reducing waste and optimizing resources. One of the more promising applications is resource allocation and optimization throughout the supply chain and AI. By using algorithms and machine learning methodologies, companies can take advantage of a level of optimization that has never before been seen across inventory management, transportation ways, and energy consumption. Once optimization has been achieved by companies, they not only can reduce costs of supply chain functions, but they also can greatly reduce the carbon footprint attributable to their supply chain efforts.

Moreover, AI can enhance the traceability and visibility of supply chains, which are both important contributors to sustainability. Improved visibility allows for better tracking

of impact on the environment and improved sustainability identification, or sustainability "hot spot" identification. The role of AI also assists with circular economy models by improving predictions of product life cycle and improving reverse logistics, both of which can reduce waste and maximize resource value, which is more in line with operational sustainability. Finally, the use of AI in SCM enables the creation of innovative sustainable products. The insights and knowledge from AI can aid in the design of sustainable products, which would contribute further to the dual goals of sustainability and market responsiveness. This alignment can ultimately create competitive gains and potentially long-term sustainable growth for firms.

Future projections

The application of artificial intelligence (AI) in sustainable supply chain management practices, known as Green AI in SCM contexts, is anticipated to change the field in several ways in the near future. Several aspects of SCM will be significantly improved via Green AI.

Various traditional supply chain practices have historically been resource-intensive ways of operating, which have led to considerable amounts of greenhouse gas (GHG) emissions. To reduce the global GHG emissions by four percent by 2030- equating to 2.4 gigatons of CO_2, or the total yearly emissions of Australia, Canada, and Japan in 2030 (PwC, 2019). One specific area where AI will assist traditional practices is predictive maintenance and asset management. The AI will develop algorithms that will be leveraged to create better predictive maintenance systems, resulting in less material waste and more opportunities to extend the life of equipment. However, AI is expected to have a significant role in enabling supply chains to operate under circular economy principles.

In terms of energy consumption, artificial intelligence (AI) should greatly help with improvements to energy efficiency of supply chain activities. Accenture (2020) reported that AI-powered energy management systems could reduce total energy consumption by up to 30% by 2025 for warehouses and distribution centers. For sustainable supplier selection, AI could incorporate complex sustainability criteria using sophisticated algorithms. Ghadimi et al. (2019) contend that AI would allow real-time evaluations of suppliers' sustainability assessments, which may considerably enhance supply chains' sustainability performance.

Finally, when it comes to predicting customer demand and managing stock, better forecasting can help reduce waste, avoid making more products than needed, and improve both efficiency and environmental care.

Another important development is using blockchain technology to make it easier to track products and share clear, trustworthy information throughout the supply chain. Saberi et al. (2019) suggest that this combination may make it possible to verify sustainable practices across the supply chain in near real-time, also reducing the occurrence of greenwashing by as much as 60%–80%, by 2027. Although this seems like a promising avenue to pursue for transparency and traceability in sustainable supply chains, we must also account for the influential factor of AI on the environment. Strubell et al. (2020) indicate that significant carbon emissions are associated with training large-scale AI models. Thus, future development of AI for sustainable SCM will mostly likely involve measures of developing low-energy consumption AI systems, considering the environmental upside of AI systems relative to the costs to carry out the implementation.

Conclusion

The rise of Green AI is not just about getting better technology—it's about changing how businesses and communities interact with the world. When companies use Green AI in their supply chains, they are improving efficiency, saving resources, and at the same time supporting the environment. It brings together smart efficiency and eco-consciousness, focusing on growth as well as sustainability. Sectors like manufacturing, healthcare, logistics, and retail are beginning to acquire the benefits. Smarter planning and better transport systems are helping them lower emissions and use fewer resources.

Achieving truly sustainable supply chains requires everyone to work together. It's not just one person's job. We need a real partnership between business leaders, who want to improve things; policymakers, who create helpful rules; researchers, who invent new tools; and customers, who are asking for greener products. This lets them meet what society wants while still being successful and ready for the future.

People who choose to lead instead of simply following are stepping into the future by embracing Green AI. By adopting eco-friendly practices, these early adopters are also setting examples of how technology and sustainability can go together. They demonstrate that being eco-friendly goes beyond rules or appearances—it's about leaving a lasting positive mark on companies, communities, and the environment.

Looking ahead, the idea is simple: if everyone in the supply chain works together, we can change what it means to be truly responsible and successful in the green economy. The possibilities are huge—and the chance to make a difference is open to all of us.

To conclude this study highlights the importance of eco-friendly practices into supply chain operations. It shows how firms can benefit from combining sustainability with smart

and efficient management. The idea is that firm that start using these green methods early can set new examples for environmental care in their industries and gain an edge over competitors in the growing green economy.

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Annexure 17.2.2

Submission Date	Submission Id	Word Count	Character Count
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9		frontiersin.org	<1	Internet Data
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23		Emerald (MCB UP) Article	<1	Publication
24		link.springer.com	<1	Publication

Reviewers Memorandum

Reviewer's Comment 1: This research reviews current literature through a conceptual framework to examine how AI is used in supply chains to meet ESG goals. It provides insights on AI's role in advancing sustainability by streamlining processes, reducing carbon footprints, and promoting eco-friendly and socially responsible practices.The paper is relevant to both academics and policymakers as it brings attention to sustainability in the Supply chain . To make the study even stronger, the methodology of the literature review can be explained in more detail by mentioning the databases used, the time period covered, and the selection criteria. This would add more clarity and transparency to the review process.

Reviewer's Comment 2: This study is well described but separate sections could be made such as limitations of the present study , future scope of research in the present topic to help other future scholars to start from. Apart from this the author would have provided the various implications for the stakeholders. Providing these sub heading related to limitation , future scope as well as the contribution not only provide guiding light to future research topics but also help in formulating the proposed research methodology for more comprehensive research on the domain.

Reviewer's Comment 3: In a part of the study the author had made a table about "Application of Green AI in SCM" in which there is repetition of the applications and variables there.Apart from this the research could have been made more context orientated because most of the studies are conducted in west which cannot be generalised to the whole world.

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Editorial Excerpt

The article has 04% plagiarism, which is within the accepted percentage as per the norms and standards of the journal for publication. As per the editorial board's observations and blind reviewers' remarks, the paper had some minor revisions, she was communicated promptly to the authors (Neetu, Saiyad, Gunjan, Anurag), and all necessary corrections were incorporated as and when directed. The comments related to this manuscript are closely aligned with the theme "Sustainable Synergy: How AI Transforms Supply Chains into Green Supply Chains" both subject-wise and research-wise.This research reviews current literature theme through a conceptual framework to examine how AI is used in supply chains to meet ESG goals. It provides insights on AI's role in advancing sustainability by streamlining processes, reducing carbon footprints, and promoting eco-friendly and socially responsible practices. After thorough reviews and the editorial board's remarks, the manuscript has been categorized and approved for publication under the "Theme Based Paper " category.

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