Article

AI and Sustainable Procurement: A Path to Green Supply Chains

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AI and Sustainable Procurement: A Path to Green Supply Chains

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Abstract: This research is about the transformative role of Artificial Intelligence (AI) in driving sustainable procurement and fostering green supply chains. As global businesses increasingly prioritize sustainability, AI offers a powerful tool for optimizing procurement processes while aligning with environmental, social, and governance (ESG) goals. By leveraging AI technologies such as machine learning, predictive analytics, and natural language processing, organizations can enhance resource efficiency, reduce waste, improve supplier transparency, and mitigate environmental and social risks. We highlight how AI supports ethical sourcing, circular economy practices, and carbon footprint reduction, contributing to more resilient and sustainable supply chains. It also addresses the challenges of integrating AI into procurement, including technological barriers, data reliability, and ethical concerns. Looking ahead, the article emphasizes the importance of aligning AI strategies with global sustainability goals and fostering collaboration across industries to achieve a greener and more ethical procurement landscape. Ultimately, AI has the potential to revolutionize supply chains, creating a future where sustainability and ethical practices are at the core of procurement decisions.

Keywords: ESG goals; environmental; supply chain resilience; ethical concerns; data reliability

1. Introduction

Sustainability has become a critical focus in supply chain and procurement operations as organizations increasingly recognize their role in addressing global environmental and social challenges [1–4]. Businesses are now under immense pressure from stakeholders, including consumers, investors, and governments, to adopt sustainable practices that reduce environmental footprints, promote social equity, and ensure long-term economic viability [3–5]. Procurement, as a central component of supply chain management, offers significant opportunities to influence sustainability outcomes [3].

The rise of Artificial Intelligence (AI) has brought transformative potential to the pursuit of sustainable procurement [4]. AI provides powerful tools for analyzing vast amounts of data, uncovering patterns, and delivering actionable insights [2]. By integrating AI-driven solutions, companies can enhance their efficiency, transparency, and accountability while aligning their supply chain operations with sustainable principles [6]. This growing synergy between AI and sustainable procurement not only addresses pressing global challenges but also paves the way for a future where business success and environmental stewardship go hand in hand [4].

2. Literature Review

2.1. Sustainable Procurement

Sustainable procurement refers to the process of acquiring goods and services in a manner that balances economic, environmental, and social objectives [1]. It goes beyond traditional procurement practices by incorporating considerations such as resource efficiency, ethical labor practices, and the reduction of negative environmental impacts [3–5]. At its core, sustainable procurement seeks to

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ensure that the decisions made during procurement contribute to long-term value creation for businesses, communities, and the planet [7]. This approach recognizes that procurement is not only a financial transaction but also an opportunity to influence positive change throughout the supply chain [4].

The principles of sustainable procurement emphasize transparency, accountability, and the integration of sustainability into every stage of the procurement process [2]. This includes assessing the lifecycle impacts of products and services, promoting fair trade practices, and fostering innovation to support sustainability goals [5]. By adhering to these principles, organizations can align their procurement strategies with broader corporate social responsibility (CSR) and sustainability objectives, ensuring that their operations reflect a commitment to environmental stewardship and social well-being [8].

Environmental, Social, and Governance (ESG) criteria play a central role in sustainable procurement [3]. These criteria provide a framework for evaluating suppliers and procurement decisions based on their environmental impact, social responsibility, and governance practices [1–3]. The environmental aspect focuses on reducing greenhouse gas emissions, minimizing waste, and conserving natural resources [2]. The social dimension emphasizes fair labor practices, respect for human rights, and community engagement. Governance criteria assess transparency, ethical conduct, and compliance with regulations [7].

2.2. The Intersection of AI and Sustainability

Artificial Intelligence (AI) has become a powerful catalyst for advancing sustainability efforts across industries, particularly within supply chain and procurement processes [6]. Its ability to process vast volumes of data, identify patterns, and generate actionable insights allows organizations to tackle complex sustainability challenges with precision and efficiency [7]. AI enhances sustainability efforts by providing tools to optimize resource use, reduce waste, and lower environmental impacts, all while improving operational efficiency and decision-making [2–6].

One of the ways AI contributes to sustainability is through predictive analytics [8]. By analyzing historical and real-time data, AI can forecast demand more accurately, reducing overproduction and minimizing waste [12]. This capability enables companies to optimize inventory levels, allocate resources more effectively, and prevent unnecessary environmental strain caused by surplus goods [9–12]. Similarly, AI-powered systems can evaluate the lifecycle impacts of products and suggest alternatives that are more sustainable, helping organizations make informed choices that align with environmental goals [11–14].

AI also plays a crucial role in identifying inefficiencies and recommending sustainable practices [14]. In energy management, AI systems can monitor energy usage and identify opportunities to transition to renewable sources, further supporting sustainability objectives [13].

Another critical area where AI enhances sustainability is supplier evaluation. AI tools can analyze suppliers' adherence to Environmental, Social, and Governance (ESG) criteria, ensuring that procurement decisions align with ethical and sustainable practices [3–9]. These tools enable organizations to identify risks such as unethical labor practices, environmental violations, or inadequate governance, promoting accountability and responsible sourcing [7].

By leveraging AI's capabilities, organizations can integrate sustainability more deeply into their operations, creating supply chains that are not only efficient but also environmentally and socially responsible [4]. This intersection of AI and sustainability represents a transformative shift, offering businesses the ability to contribute meaningfully to global sustainability goals while maintaining competitiveness in a dynamic marketplace [6].

2.2.1. Key AI Technologies in Procurement

Artificial Intelligence is transforming procurement by introducing advanced technologies that automate processes, improve decision-making, and enhance sustainability [1].

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Machine learning plays a pivotal role in procurement by enabling systems to learn from historical data and continuously improve over time [14]. This technology allows organizations to identify patterns and trends, predict supplier performance, and optimize procurement strategies [1]. By analyzing large datasets, machine learning models can provide insights into cost-saving opportunities, demand fluctuations, and supplier risks, helping organizations make more informed and strategic decisions [15].

Natural language processing (NLP) is another critical AI technology that enhances procurement by simplifying and automating communication [15]. NLP enables systems to process and understand human language, making it possible to analyze contracts, supplier documents, and compliance reports efficiently [6]. This capability streamlines the evaluation of complex documents, ensures regulatory adherence, and reduces the time spent on manual reviews. NLP can also power chatbots and virtual assistants, providing real-time support to procurement teams and fostering seamless communication across global supply chains [6].

Predictive analytics leverages AI to anticipate future trends and outcomes, making it a valuable tool for procurement planning [1–12]. By using historical and real-time data, predictive analytics can forecast demand, identify potential supply chain disruptions, and optimize inventory management [5]. This proactive approach minimizes waste, reduces costs, and ensures that procurement aligns with both operational needs and sustainability goals [5–8].

Together, these AI technologies are reshaping procurement processes by introducing efficiency, accuracy, and strategic foresight [9]. Their integration into procurement systems allows organizations to not only achieve operational excellence but also to advance their sustainability objectives, creating resilient and responsible supply chains that are equipped to meet the challenges of a rapidly evolving marketplace [10].

2.3. AI-Driven ESG Analysis: Evaluating Supplier Sustainability Credentials

Artificial Intelligence is revolutionizing the way organizations evaluate supplier sustainability credentials by offering sophisticated tools to assess Environmental, Social, and Governance (ESG) performance [3]. This capability is crucial in ensuring that procurement decisions align with ethical and sustainable practices, enabling businesses to uphold their commitments to environmental stewardship and social responsibility [10,11].

AI-driven ESG analysis begins by gathering and processing vast amounts of data from various sources, including supplier reports, regulatory filings, and external databases [13]. Through machine learning and natural language processing, AI systems can extract and analyze relevant ESG metrics, providing a comprehensive view of a supplier's sustainability performance [16]. This analysis allows procurement teams to evaluate suppliers based on criteria such as carbon emissions, energy usage, waste management, labor practices, and governance transparency [16–20].

One of the significant advantages of AI is its ability to uncover hidden risks and inconsistencies in supplier data [8]. Traditional methods of evaluating supplier sustainability often rely on self-reported information, which may not always be accurate or complete [1–15]. AI tools, however, can cross-reference multiple data sources, identify discrepancies, and flag potential issues, ensuring a more reliable assessment of a supplier's ESG credentials [16].

In addition to evaluating individual suppliers, AI can help organizations benchmark their suppliers against industry standards or sustainability goals [3]. By comparing ESG performance metrics across a supplier network, businesses can identify leaders and foot-draggers, prioritize engagement with high-performing suppliers, and develop improvement plans for those falling short [16]. This benchmarking process also supports transparent communication with stakeholders, as organizations can demonstrate their commitment to partnering with responsible and sustainable suppliers [15].

AI-driven ESG analysis not only enhances the efficiency and accuracy of supplier evaluations but also fosters long-term sustainability across supply chains [14]. By leveraging AI technologies,

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organizations can ensure that their procurement practices contribute to a greener, more equitable, and accountable global marketplace [9].

2.3.1. Monitoring Compliance with ESG Standards

Artificial Intelligence plays a pivotal role in monitoring compliance with Environmental, Social, and Governance (ESG) standards, ensuring that suppliers and procurement processes align with organizational sustainability objectives [12]. Effective compliance monitoring requires continuous assessment of suppliers' adherence to ESG criteria, a task that AI has revolutionized by automating and enhancing the accuracy of evaluations [14].

AI systems can gather and analyze large volumes of data from diverse sources, including supplier reports, third-party audits, regulatory filings, and news outlets [8–11]. By leveraging machine learning and natural language processing, these systems can identify indicators of compliance or potential violations in real time [9]. This capability enables procurement teams to proactively address risks, such as unethical labor practices, environmental violations, or governance lapses, before they escalate into significant issues [6].

Real-time monitoring powered by AI ensures that any changes in a supplier's ESG performance are promptly detected [16]. AI also simplifies the process of regulatory compliance by mapping supplier activities against global and local ESG regulations [20]. This ensures that organizations not only meet internal sustainability goals but also adhere to legal requirements. AI systems can provide actionable insights to rectify non-compliance, helping suppliers implement corrective measures and avoid penalties [17].

By facilitating consistent and comprehensive ESG compliance monitoring, AI enhances transparency, mitigates risks, and builds trust among stakeholders [7]. Organizations that integrate AI into their compliance processes are better positioned to maintain sustainable supply chains and drive long-term value for both their business and the broader community [3–12].

2.3.2. Identifying and Mitigating Environmental and Social Risks

Artificial Intelligence is transforming the way businesses identify and mitigate environmental and social risks within their supply chains, enabling proactive management of sustainability challenges [2]. Traditional risk management often relies on periodic audits and manual assessments, which may not capture emerging risks in real time [1].

AI tools can process data from environmental sensors, social media, news outlets, regulatory bodies, and supplier reports, allowing organizations to detect risks related to environmental pollution, resource depletion, human rights violations, and labor disputes [9]. Through machine learning algorithms, AI systems can identify patterns and correlations that may indicate rising risks, such as sudden changes in supplier practices, compliance violations, or emerging social unrest in specific regions [11]. This enables businesses to address problems before they escalate into costly or reputationally damaging events [8].

In addition to identifying risks, AI also plays a critical role in mitigating them by providing actionable insights for risk prevention and remediation [2]. In the social domain, AI can assess labor conditions and supply chain transparency, identifying suppliers who may be engaging in unethical practices such as child labor or unsafe working conditions [5]. By flagging these issues early, businesses can take immediate action to either work with suppliers to improve practices or seek alternative sources that align with sustainability standards [5].

2.4. Optimizing Resource Allocation with AI: Reducing Waste and Enhancing Efficiency

Traditional supply chain and procurement systems often struggle with inefficiencies, leading to overproduction, surplus inventory, and wasted resources [13]. AI addresses these challenges by providing data-driven solutions that optimize every aspect of resource use, from production to logistics, and ensure that organizations can meet demand while minimizing environmental impact.

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One of the key ways AI contributes to waste reduction is through advanced forecasting and demand prediction [13]. By analyzing historical data, real-time information, and external factors such as market trends or seasonal fluctuations, AI algorithms can predict demand with a high degree of accuracy. This helps businesses avoid overproduction and underproduction, ensuring that they only produce what is needed and minimizing excess inventory that often results in waste [16]. The ability to predict demand more precisely also enables better coordination between suppliers and manufacturers, reducing the need for rush orders or last-minute shipping, which can be resource-intensive and wasteful [13].

In addition to optimizing logistics and manufacturing processes, AI also plays a role in minimizing waste in materials management [12]. AI-powered tools can monitor inventory levels in real-time, identify slow-moving stock, and suggest more efficient ways to use or redistribute materials, thus reducing the need for waste disposal [12]. These systems can also recommend the use of recycled or sustainable materials, further supporting waste reduction and sustainability initiatives [18–20].

Through its ability to enhance forecasting, streamline operations, and minimize material waste, AI enables businesses to allocate resources more effectively and sustainably [16]. By embracing AI-driven optimization, organizations can achieve greater efficiency, reduce environmental impact, and move closer to their sustainability goals while maintaining competitiveness in an increasingly resource-conscious marketplace [18].

2.4.1. Streamlining Supply Chain Operations for Reduced Environmental Impact

Artificial Intelligence is playing a transformative role in streamlining supply chain operations, offering businesses powerful tools to reduce their environmental impact [4]. Traditional supply chain processes can often be inefficient, leading to excessive energy consumption, waste generation, and unnecessary emissions [9]. AI-driven solutions are helping organizations rethink and optimize every stage of their supply chain, from procurement to transportation, production, and delivery, ensuring a more sustainable and eco-friendly operation [12].

One of the ways AI helps streamline supply chain operations is through enhanced demand forecasting and inventory management. By accurately predicting future demand, AI minimizes the likelihood of overproduction and excess inventory, which can result in waste and unnecessary resource consumption [6],[8]. Companies can adjust production schedules and stock levels to meet demand more precisely, reducing material waste and avoiding overstock situations that require disposal or discounting [9]. This level of precision not only cuts down on waste but also contributes to more efficient resource utilization, such as energy and raw materials [12].

Another area where AI contributes to environmental sustainability is in production and manufacturing [17]. AI systems can help companies monitor energy usage in real time, ensuring that production facilities operate as efficiently as possible [3]. AI can adjust production schedules based on energy availability, moving operations to times when renewable energy sources are abundant or when energy prices are lower, thus minimizing reliance on fossil fuels [12]. Additionally, AI can predict maintenance needs for machinery, reducing downtime and improving the efficiency of production processes, leading to less waste and energy consumption [13].

Through these AI-powered advancements, organizations can streamline their supply chain operations, reducing their environmental footprint while also enhancing operational efficiency [12]. By integrating AI into supply chain management, businesses not only improve their sustainability but also gain a competitive edge in an increasingly eco-conscious market [5]. These innovations contribute to the creation of greener, more efficient supply chains, aligning business practices with global environmental goals and helping to address the urgent need for sustainable resource management [6–12].

2.4.2. Promoting Circular Economy Practices

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The concept of a circular economy emphasizes the importance of reducing waste, reusing resources, and recycling materials, ultimately promoting environmental sustainability and reducing reliance on finite resources [4]. AI provides the tools to optimize these practices by improving efficiency, extending product life cycles, and ensuring that materials are continuously reused or recycled [16].

One of the key ways AI supports circular economy practices is through intelligent product design and material management. AI-powered systems can analyze product life cycles, identifying opportunities to design goods for longevity, easy repair, and recyclability [14]. By using data from various stages of the product's life, AI can provide insights into how materials can be recovered and reused, reducing waste and conserving valuable resources [15]. This can lead to innovations such as modular product designs that are easier to disassemble and recycle, or the use of sustainable materials that can be easily reclaimed after use [16].

In addition, AI helps organizations optimize the reuse and recycling of materials by automating sorting processes and improving the efficiency of recycling facilities. Through machine learning algorithms, AI can distinguish between different types of materials, such as plastics, metals, and paper, and ensure that they are properly sorted for recycling [12]. AI systems can also predict the availability of recyclable materials, helping organizations develop more accurate recycling programs and ensuring that valuable resources are not lost to landfills [18].

AI also enhances reverse logistics, which is a critical component of circular economy models. Reverse logistics refers to the process of collecting used products from consumers for refurbishment, reuse, or recycling [19]. AI can optimize reverse logistics by predicting when products are likely to be returned, streamlining the collection and redistribution of items for reuse. Additionally, AI can identify the most efficient routes for collecting and redistributing products, reducing transportation costs and environmental impact [20].

Finally, AI can drive the development of business models that support the circular economy, such as product-as-a-service or take-back schemes [15]. By leveraging data and analytics, AI can help businesses create more sustainable models where products are leased, repaired, or resold rather than discarded. This approach encourages extended product lifecycles and minimizes waste, contributing to a circular flow of materials and energy within the economy [17]. By facilitating the adoption of circular economy principles, AI helps businesses reduce their environmental footprint, create new revenue streams, and promote sustainability throughout the supply chain [19]. As organizations increasingly recognize the value of a circular economy, AI will continue to play an essential role in ensuring that resources are used efficiently, products are kept in circulation, and waste is minimized [20].

2.5. AI-Powered Ethical Sourcing: Ensuring Transparency and Traceability in Supply Chains

One of the key ways AI enhances transparency is by enabling real-time tracking of goods as they move through the supply chain [19]. AI-powered tools, combined with Internet of Things (IoT) sensors and blockchain technology, provide end-to-end visibility, allowing businesses to trace products from raw materials to final delivery [8–20]. This data can be used to verify that suppliers are meeting ethical standards, such as fair labor practices, environmental regulations, and compliance with human rights guidelines. By tracking every step of a product's journey, companies can ensure that their suppliers are adhering to responsible practices, minimizing the risk of unethical or illegal activities going unnoticed [13].

AI also plays a critical role in analyzing large volumes of data from multiple sources to assess supplier risk and verify compliance with ethical sourcing standards [5]. Machine learning algorithms can process data from financial reports, news outlets, and social media to detect potential red flags, such as labor abuses, environmental violations, or corruption [15]. This enables businesses to identify high-risk suppliers and address issues before they escalate, ensuring that sourcing decisions align with corporate values and ethical commitments [8].

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Furthermore, AI-driven systems can enhance the accuracy of supplier audits by automating document analysis and verifying the authenticity of certifications [6]. Traditional audits are often labor-intensive and prone to human error, but AI can quickly process and cross-check supplier records against regulatory standards and sustainability benchmarks [7]. This helps reduce the risk of fraud and ensures that certifications related to environmental and social responsibility are legitimate, providing confidence in the sourcing process [7].

2.5.1. Combating Human Rights Violations and Unethical Labor Practices

One of the ways AI helps combat human rights violations is by analyzing large datasets to identify patterns of risk related to labor exploitation, such as forced labor, child labor, or unsafe working conditions [7]. Machine learning algorithms can sift through vast amounts of data from diverse sources, including news reports, social media, regulatory filings, and supplier reports, to uncover instances of abuse or exploitation that might otherwise go unnoticed [8].

AI tools also enhance supply chain transparency, enabling organizations to track the origin and movement of products from raw materials to finished goods [13]. By combining AI with blockchain technology, companies can create an immutable and transparent record of every transaction, ensuring that labor conditions at each stage of production are ethically sound [19]. This traceability allows businesses to verify that suppliers are not engaging in exploitative practices, such as low wages, unsafe working environments, or human trafficking, and provides consumers with confidence in the ethical sourcing of products [17].

In addition, AI can be used to monitor and assess supplier behavior through sentiment analysis of public reviews, employee feedback, and social media activity [20]. By analyzing these unstructured data sources, AI can provide insights into working conditions, uncovering potential labor abuses that might not be reported through formal channels [8]. This enables businesses to engage with suppliers and take corrective actions based on real-time feedback, ensuring that labor practices are continually monitored and improved [12]. By leveraging AI, organizations can significantly reduce the risk of human rights violations and unethical labor practices within their supply chains. With the ability to detect, monitor, and address issues more proactively, AI supports businesses in maintaining ethical standards and upholding human rights [6].

2.5.2. Leveraging AI for Data-Driven Ethical Decision-Making

Artificial Intelligence is significantly enhancing ethical decision-making processes within organizations by providing data-driven insights that support responsible and transparent choices [10]. AI-driven systems can also support ethical decision-making by automating the identification of ethical risks within supply chains [12].

Another key aspect of AI's role in ethical decision-making is in promoting fairness and reducing bias. In supplier selection and evaluation, AI can help ensure that decisions are based on objective, unbiased criteria, such as adherence to sustainability standards, fair labor practices, and environmental stewardship [16]. AI algorithms can be trained to recognize and eliminate bias in decision-making processes, ensuring that businesses select suppliers and partners based on merit and alignment with ethical values, rather than subjective preferences or discriminatory practices [21]. This helps foster diversity, inclusion, and fairness within supply chains and procurement activities [20].

Furthermore, AI can assist organizations in aligning their procurement decisions with long-term ethical goals, such as sustainability and corporate social responsibility (CSR) [23]. By leveraging predictive analytics, businesses can evaluate the potential long-term environmental and social impact of their procurement choices, helping to prioritize suppliers and materials that contribute to sustainable development [17]. AI-driven tools can model various scenarios, assessing the impact of different procurement strategies on resource usage, waste generation, carbon emissions, and social equity. This enables businesses to make ethical decisions that not only benefit their bottom line but also support broader societal and environmental goals [27].

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2.6. AI's Role in Minimizing Carbon Footprints: Predicting and Reducing Greenhouse Gas Emissions

One of the primary ways AI helps reduce GHG emissions is through the use of predictive analytics [23]. AI systems can analyze historical data on emissions and energy consumption, combined with real-time data from sensors and IoT devices, to predict future emissions patterns and identify potential areas for improvement [28]. By forecasting emissions based on factors such as production schedules, transportation routes, and energy usage, AI enables organizations to take proactive measures to reduce their carbon footprint before emissions reach critical levels [29]. These predictive models can help companies optimize energy consumption, adjust production processes, and implement more sustainable practices in real time [31].

AI can also optimize supply chain logistics to minimize transportation-related emissions, which are a significant contributor to overall GHG emissions [31]. AI-driven systems can calculate the most fuel-efficient routes for transportation, taking into account variables such as traffic, weather conditions, and delivery schedules [24]. By minimizing travel distances and optimizing delivery routes, businesses can reduce fuel consumption, lower carbon emissions, and reduce the overall environmental impact of their supply chain operations [19]. Additionally, AI can recommend the most sustainable modes of transportation, such as electric vehicles or rail, which produce fewer emissions compared to traditional fossil fuel-powered options [9].

In manufacturing and production, AI plays a crucial role in optimizing energy usage and reducing waste [33]. AI can monitor and analyze energy consumption patterns within production facilities, identifying opportunities for energy efficiency improvements [23]. AI-powered predictive maintenance also helps ensure that machinery operates at peak efficiency, minimizing energy waste caused by equipment malfunctions or underperformance [2]. This optimization not only reduces energy consumption but also lowers the carbon emissions associated with manufacturing processes [12].

AI-driven smart grids are another key technology in reducing GHG emissions, particularly in industries with high energy demands [26]. These grids use AI to manage the distribution of electricity more efficiently, balancing supply and demand in real-time and ensuring that renewable energy sources, such as wind or solar power, are utilized to their fullest potential [25]. AI can forecast energy demand, optimize the integration of renewable energy into the grid, and reduce reliance on fossil fuels, which are typically associated with higher emissions [12].

Furthermore, AI is helping organizations track and measure the carbon footprints of their products and services [12]. By using AI to analyze life cycle data, companies can assess the total environmental impact of their products, from raw material extraction to production, transportation, and disposal [8–12]. This level of insight allows businesses to identify high-emission stages in their product's life cycle and implement strategies to reduce emissions, such as using more sustainable materials or improving recycling practices [16].

2.6.1. Sustainable Logistics and Route Optimization

Sustainable logistics and route optimization are key strategies in reducing the environmental impact of supply chains, particularly by minimizing carbon emissions and optimizing resource use [13]. As transportation and logistics account for a significant portion of global greenhouse gas (GHG) emissions, AI is increasingly being employed to enhance sustainability efforts in these areas [11]. By integrating AI into logistics management, businesses can improve the efficiency of their operations, reduce fuel consumption, and lower the overall carbon footprint of their supply chains [19].

AI can also optimize vehicle loads to ensure that transport capacity is fully utilized, preventing underloading, which leads to unnecessary trips and increased emissions [11]. By using data to predict demand and adjust shipment sizes, AI ensures that vehicles are used at their full capacity, minimizing the number of trips needed to deliver goods [10]. This contributes to reducing the carbon footprint by optimizing resource utilization and cutting down on the frequency of transportation [10,11].

The integration of AI with electric vehicles (EVs) is another avenue for promoting sustainable logistics [9]. AI systems can support the deployment of EVs by optimizing routes and schedules to

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align with vehicle battery life and charging stations [28]. With AI, businesses can ensure that electric vehicles are utilized efficiently, optimizing battery usage and minimizing downtime caused by charging needs [19]. This further reduces emissions, as EVs produce zero tailpipe emissions, unlike their fossil fuel-powered counterparts [33].

Another key aspect of sustainable logistics involves warehouse optimization. AI can be used to improve warehouse operations by automating processes like inventory management, order fulfillment, and packaging [34]. By streamlining warehouse operations, businesses can reduce the need for excess storage space and minimize the resources required for packaging and handling [36]. Additionally, AI helps optimize the use of energy within warehouses, adjusting lighting, HVAC systems, and equipment usage to ensure energy efficiency [35].

2.6.2. AI-Enabled Energy Management in Procurement

One of the primary ways AI contributes to energy management in procurement is through the use of predictive analytics. By analyzing historical data on energy consumption patterns, AI can forecast future energy needs based on factors such as production schedules, weather conditions, and market trends [37]. This enables organizations to make more informed decisions about when and how much energy to purchase, ensuring that energy usage is aligned with actual demand [24]. AI's ability to predict energy consumption in real-time helps businesses avoid over-purchasing energy, which can lead to wasted resources, and under-purchasing, which can result in operational disruptions [25].

AI-powered optimization algorithms are also instrumental in enhancing energy procurement strategies [26]. In traditional energy procurement, decisions are often based on static contracts or pre-set agreements, which may not always be the most cost-effective or sustainable option [28]. AI, however, can continuously monitor energy prices, availability, and environmental impact across various suppliers to identify the best energy procurement deals [29]. By analyzing data from multiple sources, such as energy markets, grid demands, and renewable energy availability, AI helps procurement teams secure energy contracts that align with both cost and sustainability goals, ensuring that energy procurement is as efficient and eco-friendly as possible [30].

Another significant benefit of AI in energy management is its role in optimizing energy use within organizations [14]. AI systems can monitor energy consumption across different operations, such as manufacturing processes, office spaces, and distribution centers [19]. Through IoT sensors and real-time data collection, AI can track energy usage at a granular level, identifying inefficiencies, such as equipment running unnecessarily or lighting systems left on when not in use [8]. With this data, AI can automatically adjust energy settings, reducing consumption without affecting operational performance. These energy-saving measures contribute to both cost reductions and a lower carbon footprint [3].

AI also supports transparency and reporting in energy management. With increasing regulatory pressure around sustainability and energy usage, organizations must provide accurate data on their energy consumption and emissions [7]. AI-driven systems can automatically collect and analyze energy usage data, generate reports, and ensure compliance with environmental regulations [11]. This data can be used to track progress toward sustainability goals, such as carbon reduction targets, and can be shared with stakeholders to demonstrate the company's commitment to energy efficiency and environmental responsibility [20].

2.7. Challenges of Integrating AI into Sustainable Procurement: Technological and Financial Barriers

Integrating AI into sustainable procurement processes holds immense potential for improving efficiency and achieving environmental goals [3]. One of the primary technological barriers to integrating AI into sustainable procurement is the complexity of implementing AI systems across existing procurement frameworks [18]. Many organizations have legacy systems that are not designed to interact with advanced AI technologies. Integrating AI with these older systems can be time-consuming, costly, and technically challenging. Additionally, AI requires large volumes of high-

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quality data to function effectively [8]. For organizations to make accurate decisions about energy usage, sustainability metrics, or supplier performance, they need access to extensive data, often from disparate sources [12]. In many cases, organizations lack the infrastructure to collect and integrate this data seamlessly, making it difficult to leverage AI's full potential [13].

Another technological hurdle lies in the need for specialized AI skills within the procurement team. Implementing AI in procurement processes requires expertise in both AI technologies and procurement strategies [18]. This means that organizations must either train existing staff or hire new employees with the necessary skills to manage and optimize AI systems [12]. The shortage of skilled AI professionals, especially in the field of sustainable procurement, presents a significant challenge for businesses looking to adopt these technologies [14].

From a financial perspective, the cost of adopting AI technologies can be a significant barrier for many organizations, especially smaller businesses with limited budgets [19]. The initial investment in AI software, infrastructure, and the necessary training for staff can be prohibitively expensive. Furthermore, organizations must also consider ongoing maintenance and upgrading costs to ensure that AI systems continue to perform at optimal levels [19].

Despite these barriers, businesses that manage to overcome them can unlock significant opportunities for sustainability improvements and operational efficiency [9,10]. Developing a clear strategy, investing in the necessary technological infrastructure, training staff, and ensuring ethical AI practices will help organizations harness the full potential of AI in sustainable procurement [17]. However, addressing the technological and financial challenges head-on is essential for realizing the long-term benefits of AI in fostering a greener, more efficient procurement process [19].

2.7.1. Ethical Concerns in AI Deployment

The deployment of Artificial Intelligence (AI) in procurement and sustainability initiatives, while promising substantial benefits, also raises a range of ethical concerns that must be addressed to ensure responsible and fair usage [32]. One of the most pressing ethical concerns in AI deployment is the issue of bias in AI algorithms. AI systems are only as unbiased as the data they are trained on. If the data fed into AI models contains biases whether related to race, gender, geography, or supplier preferences those biases can be perpetuated or even amplified by the AI [23]. This could lead to discriminatory practices, such as favoring certain suppliers over others based on biased data, or failing to account for underrepresented communities. Such biases can undermine the fairness of procurement decisions, particularly when AI systems are used to assess supplier performance or evaluate sustainability practices [23–32].

Therefore, the ethical deployment of AI in sustainable procurement also involves ensuring that AI technologies contribute to long-term sustainability goals without creating harmful environmental or social consequences [27]. The use of AI to prioritize short-term efficiency gains at the expense of long-term sustainability could exacerbate issues like environmental degradation, inequality, or exploitation of vulnerable communities [27],[36]. As such, businesses must adopt an ethical framework for AI that aligns with broader sustainability goals, ensuring that AI technologies are used to promote environmental stewardship, social responsibility, and economic equity [23–32].

2.7.2. Ensuring Data Accuracy and Reliability

One of the first steps in ensuring data accuracy is the establishment of robust data collection processes [13]. AI systems require large volumes of data from multiple sources, including supplier performance metrics, sustainability assessments, and environmental impact reports. To ensure that this data is accurate, businesses must develop standardized procedures for collecting data and ensure that all data sources are reliable [9]. This may involve working closely with suppliers to establish clear data reporting guidelines and ensuring that data is collected in a consistent manner across different departments or regions [12]. For example, when collecting data on a supplier's carbon emissions or waste management practices, it is important to use standardized measurement frameworks to ensure comparability and reliability [17–20].

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Data cleansing is another critical component of ensuring accuracy and reliability [33]. Over time, data can become outdated, incomplete, or inconsistent due to human error or changes in operational conditions [7]. AI systems rely on up-to-date and consistent data to produce accurate insights, so businesses must implement data cleansing procedures to identify and correct any errors or discrepancies in the dataset [19]. This may involve removing duplicate entries, correcting data entry mistakes, or filling in missing information. By maintaining a clean and consistent dataset, businesses can ensure that the AI systems are working with the most accurate and relevant data available [16].

Data integration is another challenge when ensuring accuracy and reliability. In sustainable procurement, data often comes from diverse sources, such as suppliers, internal systems, and external databases [29]. Ensuring that these disparate data sources are integrated effectively can be complex, particularly when data is structured differently or stored in various formats. Businesses must implement data integration strategies that standardize data formats, synchronize data from multiple sources, and eliminate silos to create a unified dataset that can be fed into AI systems [32]. This will help ensure that all relevant data points are captured and that AI systems are using the most comprehensive and accurate dataset possible [6].

Therefore, businesses must prioritize data security as part of their strategy for ensuring data accuracy and reliability [5]. Accurate data is of little value if it is vulnerable to tampering, unauthorized access, or cyberattacks. Therefore, robust cybersecurity measures must be in place to protect sensitive data, particularly when dealing with supplier information or sustainability metrics [9]. Data encryption, secure storage solutions, and access control protocols can help safeguard the integrity of the data and prevent any potential breaches that could compromise its accuracy [10,11].

2.8. The Future of AI in Sustainable Procurement: Emerging Trends and Innovations

One of the emerging trends in AI-driven sustainable procurement is the increased use of predictive analytics to forecast environmental and sustainability outcomes [14]. AI systems will be able to analyze vast amounts of data and predict future trends in areas such as supplier sustainability, resource consumption, and carbon emissions [16].

AI-powered supplier collaboration is another key innovation that will shape the future of sustainable procurement [9]. As businesses become more focused on sustainability, they will increasingly seek to collaborate with suppliers to jointly achieve sustainability goals [24]. AI systems will enable real-time communication and collaboration between buyers and suppliers, providing data-driven insights that help both parties identify opportunities for sustainability improvements [23].

Therefore, the integration of AI with Internet of Things (IoT) technologies is expected to further enhance sustainable procurement practices [9]. IoT devices can collect real-time data on various aspects of the supply chain, such as energy consumption, waste generation, and transportation emissions [27]. By combining this data with AI's predictive capabilities, businesses can gain deeper insights into the environmental impact of their procurement decisions and optimize operations to reduce their carbon footprint [23].

2.8.1. Aligning AI Strategies with Global Sustainability Goals

One of the key aspects of aligning AI strategies with global sustainability goals is ensuring that AI initiatives are specifically designed to support the environmental sustainability objectives of the SDGs [17–20]. For example, SDG 12, which focuses on responsible consumption and production, emphasizes the need for businesses to minimize waste, reduce resource consumption, and adopt circular economy practices [20]. AI can play a pivotal role in this by enabling better resource management, waste reduction, and supply chain optimization [20]. AI-powered systems can predict demand more accurately, allowing businesses to reduce overproduction and minimize waste [3]. By implementing AI technologies that optimize the use of resources and reduce environmental impact, businesses can directly contribute to achieving SDG 12, ensuring that their procurement strategies align with broader sustainability goals [3].

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In addition to environmental goals, aligning AI strategies with the social sustainability aspects of the SDGs is equally important [7]. SDG 8, which focuses on promoting decent work and economic growth, and SDG 10, which aims to reduce inequality, can be advanced through the use of AI in procurement [7]. AI can help identify and evaluate suppliers that adhere to ethical labor practices, ensure fair wages, and foster diversity and inclusion [12]. For example, AI-driven supplier evaluations can include social criteria, such as labor rights and human rights compliance, ensuring that businesses choose partners who contribute positively to social development [3]. By leveraging AI to promote ethical sourcing and fair labor practices, organizations can directly contribute to social sustainability and work toward achieving SDG 8 and SDG 10 [3–12].

Furthermore, AI strategies must also align with transparency and accountability—key elements of SDG 16, which promotes peace, justice, and strong institutions [18]. AI technologies can be used to enhance the transparency of procurement processes by providing real-time data on supplier performance, sustainability credentials, and compliance with ethical standards [34]. This transparency allows businesses to hold suppliers accountable for their actions and ensures that procurement decisions are based on reliable, verifiable information [28]. By using AI to foster transparency, organizations can build trust with stakeholders, promote good governance, and contribute to SDG 16 [12–17].

Finally, to track progress and ensure alignment with sustainability goals, businesses should regularly evaluate the outcomes of their AI strategies [11]. Implementing key performance indicators (KPIs) related to sustainability, such as reductions in carbon emissions, improvements in ethical sourcing, or increased resource efficiency, will help organizations measure the effectiveness of their AI initiatives [14]. Continuous monitoring and reporting on these KPIs will provide businesses with the insights needed to refine their AI strategies and ensure they remain aligned with evolving global sustainability goals [33].

2.8.2. Building Resilient and Green Supply Chains

Building resilient and green supply chains has become an imperative for businesses that aim to thrive in a rapidly changing and environmentally conscious world [23]. As supply chains are increasingly exposed to disruptions caused by factors like climate change, geopolitical instability, and economic fluctuations, organizations are recognizing the need to create supply chains that are both sustainable and adaptable [9]. Resilience and sustainability go hand-in-hand, as businesses that invest in resilient supply chains can better withstand disruptions while simultaneously reducing their environmental impact [2–13]. Artificial Intelligence (AI) has emerged as a critical enabler of this transformation, helping businesses build supply chains that are not only more adaptable and robust but also greener and more sustainable [16].

At the heart of building resilient and green supply chains is the need for organizations to optimize their operations for sustainability while maintaining flexibility and responsiveness in the face of disruptions [4]. One of the key ways AI contributes to this goal is through predictive analytics, which enables businesses to anticipate potential supply chain risks and disruptions [28]. By analyzing historical data and external variables such as weather patterns, geopolitical developments, and economic indicators, AI can predict and identify possible supply chain bottlenecks or disruptions before they occur. This foresight allows companies to proactively take corrective actions, such as finding alternative suppliers, adjusting inventory levels, or shifting production schedules, to ensure that their supply chains remain resilient despite external shocks [33]. Predictive capabilities also support decision-making processes around sustainability by helping companies forecast demand more accurately, leading to more efficient production practices and minimizing waste [34].

Building resilience in green supply chains also involves enhancing supplier collaboration and transparency [7–13]. One of the major challenges in building sustainable supply chains is ensuring that suppliers adhere to environmental standards and ethical practices [7]. AI plays a vital role in improving supplier relationship management by facilitating real-time communication and providing data-driven insights into supplier performance [12]. AI systems can analyze data from a variety of

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sources, including sustainability reports, environmental certifications, and compliance records, to evaluate the environmental and social performance of suppliers [37]. This helps organizations identify and partner with suppliers who align with their sustainability objectives, ensuring that the entire supply chain contributes to greener and more resilient practices. Moreover, AI enables businesses to monitor supplier performance continuously, ensuring that sustainability standards are met and mitigate the risk of sourcing from suppliers with unsustainable practices [13–37].

Supply chain diversification is another essential strategy for building resilience in green supply chains [13–17]. In the face of disruptions, such as natural disasters, trade conflicts, or supply shortages, businesses that rely on a single supplier or region are at a higher risk of experiencing supply chain breakdowns [2–8]. AI can help businesses assess the risks associated with their supply chain dependencies by analyzing factors such as geographic location, political stability, and supplier reliability [8–17]. By using AI to identify potential vulnerabilities, businesses can diversify their supplier base, source materials from different regions, and develop contingency plans to ensure that supply chains remain intact during times of crisis [12–32]. This level of diversification not only improves resilience but also helps organizations maintain sustainable sourcing practices, as AI can assist in finding eco-friendly suppliers in alternative regions or markets [7–13].

3. Conclusion

AI's contribution to sustainable procurement is evident in various ways, from predicting and mitigating environmental risks to enabling ethical sourcing practices. By harnessing AI technologies such as predictive analytics, machine learning, and natural language processing, businesses can evaluate supplier sustainability, identify environmental and social risks, and optimize procurement strategies. These capabilities ensure that procurement decisions are not only efficient but also aligned with environmental, social, and governance (ESG) criteria, promoting long-term sustainability goals. Furthermore, AI-driven insights can help organizations make more informed choices, reduce waste, lower carbon emissions, and improve supply chain resilience in the face of disruptions, leading to a greener and more ethically responsible supply chain.

While the potential of AI in sustainable procurement is clear, the successful implementation of AI-driven strategies requires businesses to take specific steps toward fostering greener and more ethical supply chains. First and foremost, companies must commit to integrating sustainability into their AI strategy, ensuring that AI tools are designed and deployed with a clear focus on environmental and social responsibility. This includes incorporating sustainability metrics into procurement decision-making, choosing suppliers who meet ESG criteria, and continuously monitoring and evaluating supply chain performance to identify areas for improvement. Additionally, businesses should invest in the training and development of personnel to ensure they are equipped to effectively leverage AI technologies in support of sustainability goals.

As we move forward, it is essential that businesses continue to invest in research and development to explore new AI innovations that can further enhance the sustainability and resilience of supply chains. AI has the potential to revolutionize procurement, but it must be harnessed in ways that align with environmental stewardship, social responsibility, and ethical governance. By embracing AI-driven solutions, organizations can play a leading role in shaping a more sustainable and equitable global economy.

Therefore, the journey toward a greener and more ethical supply chain requires commitment, innovation, and collaboration. AI offers an unparalleled opportunity to achieve these objectives, providing organizations with the tools they need to make more sustainable and socially responsible procurement decisions. By integrating AI into sustainable procurement strategies, businesses can contribute to a brighter, more sustainable future for all, helping to ensure the health and prosperity of the planet for generations to come.

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