SMART LOGISTICS: THE ENVIRONMENTAL IMPACT OF TECHNOLOGY-DRIVEN SUPPLY CHAINS

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Abstract

A holistic advancement drives the logistics industry where innovative technologies, including Blockchain and artificial intelligence (AI) and the Internet of Things (IoT), work in tandem. The growing pressure on environmental issues has led businesses to implement sustainable approaches for lowering their carbon emissions along with waste production and return management (Ogunrinde et al., 2025). The current logistics industry and other organizations face sustainability requirements through smart technologies such as Eco-friendly packaging and route planning and energy management systems. The paper examines how businesses apply these technologies throughout their supply chain operations and inventory control, together with transportation systems and warehouse systems, to generate sustainability while cutting waste and maximizing resource efficiency, and enhancing return optimization. AI based route optimization and electric vehicles will substantially reduce environment pollution. The AI-based route optimization reduces emissions by minimizing travel time, traffic jams, and waiting time, while electric vehicles (EVs) eliminate carbon emissions, according to Chung et al. (2021). These methods enhance sustainability by improving energy consumption, reducing carbon footprints, and improving air quality.

Keywords: green logistics, supply chain management, blockchain technology, artificial intelligence, sustainability, internet of things, automation

Introduction

The rapid advancement in Information Technology (IT) has developed the Internet of Things (IoT), Artificial Intelligence (AI), Blockchain, and Automation, which play a pivotal role in various sectors, including the logistics sector. LOGISTICS refers to movement of goods and personnel between businesses, end to end supply chain operations such as raw material procurement, inventory management warehousing and transportation. The logistics sector demonstrated substantial growth during the past year owing to worldwide developments. Modern smart systems have revolutionized all operations within logistics systems (Zavisa, 2024) that smart logistics practices in business operations streamline operations while making processes more efficient and environmentally friendly and eliminate labour needs and documentation while boosting output and transforming data retrieval methods and analysis capabilities together with enhanced control systems and higher profitability, which drives fast organization growth. Smart technology implementation in logistics continues to evolve through an ongoing process that drives operational improvement and creates environmental sustainability, and lowers carbon footprint. The definition of sustainability in logistics relates to how logistics service providers and their clients conduct practices and implement strategies to minimize environmental effects and achieve both economic success and social and sustainability benefits for their activities (Rodrigue. et al.2016). Modern logistics faces lots of problems that affect operational efficiency and sustainability. For instance, the supply chain is driven by global disruptions. Number of issues with current transportation systems, such as traffic congestion, parking problems with limited parking space, longer commuting time, high level of CO_2 emission, increased number of accidents, and others. Shortages of skilled labour, truck drivers, and warehouse workers increase operational hurdles. To improve the operational efficiency in supply chain management and transportation systems, it is necessary to increase the use of information technologies like IoT, AI, Blockchain, and Automation.

Current logistics operations can benefit from implementing green transport methods based on electric vehicles combined with hybrid vehicles yet supported by alternative fuel solutions to minimize environmental impacts. Careful use of Collaborative Robots (Cobots) goes alongside Warehouse management systems, the Internet of Things, and Automated Picking tools in warehouse operations.

This article **aims** to examine how smart logistics applications such as IoT, AI, Blockchain, and Automation and robotics optimize supply chain operations, contribute to sustainability by reducing carbon emissions and improving efficiency.

The following **objectives** have been set to achieve the aim:

1. To explore the role of smart applications such as Artificial Intelligence, Internet of Things, Blockchain and Automation and Robotics in optimizing logistics operations and reducing carbon footprints.
2. To evaluate the environmental benefits of energy-saving technologies in warehouse and transportation. How electric vehicles and alternative fuels reduce environmental footprints of logistics.
3. To identify the challenges and opportunities while implementing these technologies.

Research object and methods

Research object: Smart technologies in logistics for sustainability of supply chain.

Research methods. The scientific literature review aims to explore the role of smart technologies in promoting environmentally sustainable supply chain management. The review aims to understand how smart applications such as

Artificial Intelligence, the Internet of Things, Automation and Robotics, and Blockchain affect the environmental performance of supply chains. First, 40 articles were reviewed from online databases, including ScienceDirect, Google Scholar, and ResearchGate, focusing on topics like “smart logistics in supply chain management”, “green logistics,” and “use of IoT in logistics,” which were published between 2016 to 2025. From these, 13 relevant papers were selected for detailed analysis. The selected papers were studied to understand how these technologies reduce carbon emissions, save energy, and improve efficiency in logistics operations. This approach is suitable because findings from multiple studies, offering a clear understanding of these technologies, contribute to sustainability and identifying challenges and opportunities for improvement.

Smart Technologies in Logistics for Sustainable supply chains

The role of the Internet of Things in Sustainable supply chains. The Internet of Things (IoT) describes a linked operation of multiple tools and vehicles equipped with sensor technology and programming to perform data exchanges. The alarm clock functions through IoT by activating window control and starting both the coffee machine and water heater operations (Oladimeji et al., 2023). A monitoring system powered by IoT performs in the background to enable smooth operations. The Internet of Things manages to transform practically all modern industrial sectors, including retail and transportation. Sustainability, along with waste reduction, becomes possible, and efficiency increases while carbon footprints decrease because of IoT's advantages in supply chain management over competitors. Real-time carbon measurement through IoT sensors enables serial numbers as well as location and temperature tracking to prevent waste from supply chains (Ogunrinde et al., 2025). The real-time tracking of goods along with vehicles and return materials in supply chain management happens through IoT devices. The installation of air quality and emissions sensors on vehicles detects operational inefficiencies that trigger immediate action by the companies to decrease emission levels. Route Optimization occurs through the use of IoT sensors, GPS tracking hardware, traffic monitoring systems, and weather data integration systems. The optimized delivery system enables paths of transportation to become more efficient, and fuel usage is minimized thus decreasing environmental emissions. Smart Fleet Management (SFM) can real time monitoring of vehicles' conditions, fuel usage, driver behaviour, and tire pressure. Plastic Crates combined with RFID tags or Barcodes serve the purpose of efficient Warehouse Management for inventory tracking (Casella et al., 2022). The plastic crates demonstrate durability and minimize environmental harm while being environmentally sustainable. Industrial applications of cold chain monitoring technologies enable proper temperature control for food and pharmaceutical goods during storage and transport because this prevents waste and decreases both spoilage and energy usage. Every logistician can access the Cryogenic Chamber as the environment-friendly solution for enduring cold chain operations. The Artic Fox Cryogenic Chamber operates as a flexible changing system. The system of transport chest and docking tower with refrigeration unit and software and storage devices forms an energy-efficient continuous cold chain system.

The deployment of IoT within green innovation logistics produces sustainable outcomes because it enhances visibility while generating useful information for managerial choices. By implementing this technology companies can decrease transportation mileage and cut down fuel usage while using Robots together with Sensors and RGID Tags (Casella et al., 2022).

Blockchain Technology. Blockchain is a distributed computing technology. The digital technology Blockchain establishes secure accounting of data which enables reliable observability of products and services throughout supply chain operations, according to Choi et al. (2022). Bit coin represents the initial Blockchain system ever created. The transparency and sustainability of logistic processes improve through Blockchain technology in this era of industry 4.0 because it creates unchangeable decentralized proof of transportation activities. Blockchain technology provides SCM with its most substantial advantage through enhanced transparency while ensuring complete visibility of product movements. Transactions become faster and less expensive since decentralized systems abolish the requirement for intermediaries and brokers. The decentralized approach improves both supply chain operation efficiency and reduces expenses for business consumers. Companies benefit from Blockchain-based tracking to optimize routes and minimize delays as well as cut down product wastage through real time goods visibility. The digital storage of records cuts down paperwork thereby minimizing the need for paper products in addition to conserving forests while decreasing the manufacturing requirements for paper products. Through the application of Smart contracts on Blockchain technology for inventory tracking, organizations can stop overstocking and understocking and, therefore, lower the need for excess production and transportation. IBM Blockchain technology serves Walmart in tracking the entire path between farms and retail locations. The strong security and reliability of blockchain technology positions it perfectly for managing supply chain data that requires high-level protection (Fernandez, 2025). Advanced encryption, together with validation methods, protects Blockchain data from alteration because the system prevents unauthorized changes. The enhanced security provided by this system creates strong barriers against hacker and cybercriminal attempts to enter supply chain systems and extract data. The system allows Supply Chain Stakeholders to improve their joint work effectiveness through a centralized information sharing platform. The integration enables better communication and enhanced cooperation between suppliers and all stages of product production, which leads to better supply chain management and enhanced customer satisfaction. The implementation of Blockchain technology within the Supply Chain Management Code helps organizations build sustainable and ethical business practices. The supply chain stakeholders can utilize Blockchain to confirm product origins and authentications, which guarantees sustainability and ethical production sourcing.

The use of Blockchain technology gives supply chain management the potential to experience revolutionary changes by allowing owners to see through processes more effectively and boost operational efficiency while establishing secure environments with stronger collaborative partnerships between stakeholders (Suryalakshmi et al. 2021).

AI-powered efficiency: Reducing waste and optimizing resources. Artificial intelligence is the science of creating computers and machines that perform human-like intelligent processing tasks and handle enormous datasets beyond human capabilities. Artificial Intelligence (AI) growth presents unmatched speed in transforming transportation and all other existing industries to make productivity advancement possible. AI involves complex computational approaches that imitate the processes of the human brain. The aviation industry uses AI solutions to solve four major issues: growing passenger traffic, increasing carbon dioxide pollution and aviation incidents, and environmental losses. Both numerical and verbal information have grown excessively abundant, yet organizations now benefit from solving these issues effectively and conclusively. Through process automation, Artificial Intelligence transforms logistics operations, improving efficiency and promoting sustainability. Predictive maintenance through AI enables automated warehousing functions that demand forecasting with various other applications to boost operational efficiency while simultaneously lowering expenses and environmental degradation levels (Burnham, 2024). Machine learning algorithms enable automated warehouse storage management, whereas AI-based predictive maintenance decreases operational downtime as well as decreases waste output. Through its demand forecasting capabilities, AI helps organizations keep inventory balanced, which produces highly effective supply chain operations, According to Sun et al. (2024), dynamic route planning enabled by AI lowers transportation emissions and reduces fuel use in logistics, which results in greener transportation operations. Through AI reverse logistics the sustainability improves because it optimizes the management of waste in addition to resource recovery activities during reverse supply chain operations. Technology advances within Artificial Intelligence produce improvements in supply chain efficiency as they minimize costs and help create sustainable business practices. The top global online retailer, Amazon makes use of AI to improve logistical operations as their primary business focus. The AI-based algorithms of the company display accurate future demand predictions to optimize inventory management. The key strength of Amazon Warehouse stems from its AI-powered truck management system that uses robotic components to handle all product retrieval and packaging tasks, leading to efficient, mistake-free operations. The media often identifies Amazon as the business using approximately 200,000 robots within its current storage system, *according to Deutsche Bank's estimate* (Edwards, 2020). AI technologies appear in both delivery drones and self-driving vehicles as the company works on their development for operational efficiency together with safety protocols. Partnerships between organizations and Big Data smart technology allow them to obtain comprehensive environmental insights regarding their supply chain operations. Organizations can build strategic paths from collected energy consumption records together with waste generation and emission metrics through data analytical procedures for making sustainable supply chain operational choices regarding energy utilization and waste generation. Such operations provide organizations with essential progress toward addressing climate change. The majority of organizations generate high waste levels, which results in damaging emissions to the environment. This, in turn, results in a loss of biodiversity and other negative effects on the ecosystem. Improving the current environmental cluster score remains essential, along with designing new emission control methods for all companies.

Automation and robotics. The definition of a robot includes a programmable device that executes tasks either autonomously, such as Robotnik, or semi-autonomously. Automation refers to technology that performs operations with or without requiring human presence (Banur et al., 2024). Sustainable development within the logistics sector depends on automation because the technology optimizes operational efficiency and reduces waste to enhance productivity levels. Energy prices decrease along with carbon footprint emissions while workforce numbers decrease because AI robots, together with analytical tools and travel planning software, operate automated systems. Business automation of inventory management and order fulfilment processes and shipment activities leads to enhanced logistics sustainability and reduced costs and environmental benefits. The application of this technology demonstrates how it effectively decreases operating costs and develops operational performance. General agreement reflects that Amazon obtained better productivity outcomes from Kiva robot integration in its fulfilment centres, with 22 million US dollars in annual cost savings per facility, according to the Deutsche Bank grant (Burnham, 2024) The logistical real-time capabilities of Alibaba Cloud enable Cainiao Network to deliver global delivery within 2-3 days to buyers and sellers by completing initial delivery miles (Tan, 2018). Advanced technology led to the development of innovative solutions since it improved logistics along with transportation systems and organizational competitiveness.

Research results and discussion: challenges and future

Smart technologies like the Internet of Things, Artificial Intelligence, Blockchain technologies, and Automation and Robotics have a significant impact on supply chain management by enhancing efficiency and accuracy. Smart applications applied for inventory management, demand forecasting, and route optimization reduce cost and waste. These technologies enable real-time tracking, forecasting, and decision-making, which allow businesses to respond faster to market changes, improve customer satisfaction, and initiate more sustainable and reliable supply chains. AI-powered applications such as Machine Learning algorithms (analyse historical sales data and external future to enhance forecasting), and Neural Network and deep Learning (detect complex patterns in consumer behaviour) enhance forecasting accuracy. It minimizes waste by avoiding overproduction, optimizing supply chains, and predicting energy needs. It reduces unnecessary energy consumption and returns. The use of advanced information and communication technologies (ICT) can create sustainable intelligent transportation systems (Ressi et al., 2024). EVs, powered by

renewable energy sources, help lower reliance on fossil fuels like biofuels, hydrogen, and natural gas, offering cleaner options for transportation. The adoption of these technologies supports the global efforts to achieve long-term environmental goals and a more sustainable future.

Challenges. The Adoption of smart technologies has become a popular issue for every business, including the logistics sector. Implementation of smart technologies in supply chain management has several challenges, involving high primary investment cost, as implementing smart technologies like AI, IoT, Blockchain, and Automation require high capital (Lu et al., 2021). Integrating these Technologies with the operational regulatory system can be complex and costly. Additionally, issue about data and security privacy in SCM. The lack of skilled workers to manage these technologies is a major concern. These technologies also as environmental and ethical concerns such as energy consumption, electronic waste, and the implementation of these technologies also leads to job replacement, which causes the business to adopt these applications. However, with efficient planning and investment, companies can create a way to sustainability and enhance efficiency.

Future. As environmental concerns companies required more strategies to adopt smart technologies to achieve their sustainability goals and to determine customer preferences and regulatory framework. In coming years, Technologies such as AI, IoT, Blockchain, and automation will become more necessary to logistics operations, and more innovations in these technologies will provide even greater opportunities for business to optimize their supply chains and enhance their sustainability efforts. In the future, innovations such as 5G, augmented reality, Autonomous vehicles and drones, and smart warehouses will improve logistics operations by offering faster and reliable internet connections, by providing workers with real-time information through AR glasses or mobile devices (Boute and Udenio, 2021). Advancements in vehicles and drones reduce costs and enhance delivery efficiency. For instance, Willot is going to develop battery-free printable sensor tags to monitor products like groceries, apparel, and Pharmaceuticals from their sources to stores and homes. In coming years, assess more integration between products. The carbon accounting tools will allow product intelligence to deliver on the vision of dynamic dashboards so that every manager of logistics manager can see the carbon footprints in real time. These technologies foster collaboration between stakeholders such as customers, suppliers, regulatory, and other third parties by providing real-time data, transparency. This collaborative approach helps to create a more sustainable, circular economy by maintaining the ongoing circulation of products and materials through the supply chain, minimizing waste and reducing the environmental economy.

Conclusions

The logistics industry may greatly improve sustainability through the use of smart technologies like automation, Blockchain, the Internet of Things, and artificial intelligence (AI). By increasing productivity, cutting carbon emissions, and eliminating waste, these technologies aid in supply chain operations optimization. More energy-efficient transportation systems are made possible by AI-driven solutions like demand forecasting and route optimization, while IoT offers real-time tracking and data-driven insights that improve operational transparency and lessen environmental effects. Blockchain helps by improving traceability and transparency, which guarantees more moral and sustainable business operations. Additionally, automation and robotics create a more sustainable logistics environment by streamlining procedures, lowering expenses, and using less energy.

Notwithstanding the significant advantages, there are obstacles to the widespread use of these smart technologies, including high upfront costs, the requirement for highly qualified personnel, and worries about privacy and data security. However, these obstacles can be removed with careful planning and ongoing creativity. Future technologies like 5G, driverless cars, drones, and smart warehouses will present even more chances to streamline operations, lessen environmental impact, and build a more sustainable, circular economy as the logistics industry shifts toward greater sustainability. In the end, smart logistics technology' continued development will be essential to advancing global sustainability initiatives and helping companies meet their long-term environmental targets.

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