SMART TECHNOLOGIES IN SUSTAINABLE LOGISTICS: A GREENER FUTURE FOR SUPPLY CHAINS

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Abstract

Sustainability has become a major focus of supply chains around the world. Carbon-neutral supply chains are an essential component of a clean and healthy planet for future generations. An increasing number of countries are making pledges to reduce their emission to net zero in the coming decades. Regulatory and consumer pressures have driven the logistics industry to adopt smart technologies for sustainable operations. This paper explores how blockchain, AI, IoT, and automation modify the supply chain to reduce carbon emissions and optimize energy usage. Additionally, electric and hydrogen-powered vehicles, drone deliveries, and robotics play a crucial role in reducing the environmental footprints of logistics operations. Yet, these innovations face certain barriers that need to be overcome, such as the cost of implementing new technologies, cybersecurity risks, and lack of a skilled workforce. This study highlights Tesla's successful implementation of green logistics solutions. The findings suggest that combining smart technologies with sustainable logistics strategies is important to achieve long-term profitability and environmental responsibility.

Keywords: smart technologies, sustainable logistics, AI, IoT, automation, and robotics benefits

Introduction

Smart technologies (STs) refer to the applications of Artificial Intelligence (AI) and data science technologies, such as Machine Learning (ML), Big Data (BD), to create cognitive awareness of an object (e.g., a system) with the support of information and communication technologies, e.g., the Internet of Things (IoT), and Blockchain (BC), etc. (Chung, 2021). Sustainability refers to "meeting the needs of present without compromising the ability of future generations to meet their own needs" (1987, United Nations Brundtland Commission). So, smart technologies in sustainable logistics refer to the use of AI, IoT, ML, and blockchain to enhance operational efficiency, optimize resources in logistics, and create intelligent systems that are environmentally, socially, and economically sustainable. The logistics and transport sector is a major contributor to global carbon emissions. From freight forwarding to cargo handling and last-mile deliveries, conventional logistics relieved fossil fuel, excessive packaging, and energy-intensive systems, leading to severe environmental consequences (Chen et al, 2024).

Due to growing environmental concerns, governments worldwide are implementing strict carbon reduction policies to lower greenhouse gas emissions and encourage eco-friendly business operations. As a result, businesses are under pressure to adopt sustainable logistics practices. Consumers are also playing a key role; they now prefer brands that prioritize eco-friendly operations. The latest technologies transform logistics by optimizing routes, increasing transparency, reducing emissions, and improving energy efficiency. AI-driven analytics can minimize fuel consumption, IoT-enabled sensors can track real-time emissions, blockchain ensures ethical sourcing, and automation enhances warehouse efficiency. By integrating these technologies, companies can achieve greener supply chains, lower operational costs, and a more sustainable future for logistics.

Research Object: Smart technologies in sustainable logistics.

Research aim is to explore smart technologies' influence on sustainability in logistics while addressing the challenges, opportunities, and future perspectives of their application.

Research objectives:

1. To study the role of smart technologies like Artificial Intelligence, the Internet of Things, Blockchain, and Automation in enhancing sustainability in logistics and supply chain operations.
2. Explore the key challenges that hinder the adoption of smart technologies in green logistics.
3. Investigate future trends and innovations in smart and sustainable logistics.

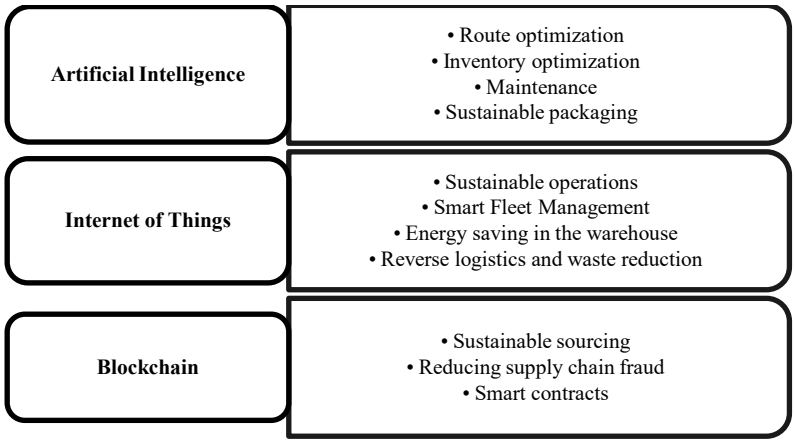
Research methodology.

The literature review used a formal, systematic process, to identify and screen articles on addressing my topic of review. I searched for articles in the two databases named Science Direct and Research Gate by using the terms smart technologies, sustainable logistics, AI, IoT, Automation and Robotics. These terms were keyed in the databases to limit the search results to more relevant articles. Relevant articles included the papers published in the 10 Years [2015-2025].

The study follows a secondary data analysis method. A total of 35 articles from the search were screened and assessed based on the title and abstract. I excluded articles not focusing on sustainable and smart technologies in logistics and reducing the number of relevant articles to 16. The literature is critically examined to identify the key benefits, challenges, and future trends of implementing smart technologies to reduce carbon emissions, optimize supply chain efficiency, and promote circular economy practices.

Research results and discussion

The scientific literature analyses the various smart technologies that contribute to more sustainable logistics operations. The application of smart technologies and their benefits in logistics are presented in Figure 1.



Source: compiled by the author

Fig. 1. Smart technologies for sustainable logistics

AI is transforming the logistics industry. It offers innovative solutions and sustainable performance. By employing AI capabilities, logistics stakeholders can enhance decision-making processes, optimize resource utilization, and minimize environmental impacts. It helps forecast demand accurately, optimize transport routes, and manage inventories in such a way that reduces emissions and waste (Kale, 2025).

*Route optimization***.** AI-driven route optimization algorithms support real-time data processing to calculate the most efficient way for delivery routes. These algorithms consider various factors, such as current traffic conditions, road closures, weather conditions, and delivery time windows, to adjust the route in real time. By using the incoming data from the GPS systems and traffic sensors, AI algorithms can find the fastest and most fuel-efficient routes, helping drivers avoid congestion and delays (Kale, 2025). AI can help to optimize the maximum capacity of the vehicle and most effective loading arrangements and make plans to reduce the number of trips. It not only saves the transportation cost but also cuts down the greenhouse gases emissions.

*Inventory optimization***.** AI analyzes vast amounts of historical sales data, seasonal demand and trends, market conditions, and human behavior to predict future demand accurately, which ensures that businesses maintain the right inventory levels and prevent overstocking and stockouts. Automated inventory replenishment enables real-time monitoring and timely restocking, minimizing human errors and supply chain disruptions (Kale, 2025). By ensuring that the right products are available at the right time and in the right quantities, AI helps minimize excess inventory, prevent obsolete items, and reduce the environmental impact of overproduction and disposal.

Sustainable packaging with AI. Sustainable packaging is a growing focus for businesses aiming to reduce environmental impacts. AI algorithms analyze product dimensions and recommend the best possible packing size, reducing excess material use. This helps in reducing the excess material use (Zhang, 2022).

AI for predictive Maintenance. It is another way of AI that contributes to sustainable logistics by ensuring that everything operates efficiently. Despite relying on scheduled maintenance checks, AI-based Machine Learning analyzes data from IoT sensors in vehicles to detect the signs of mechanical failures. It predicts possible malfunctioning before it happens, which allows logistics companies to fix small issues before they become costly (Theissler et al., 2021). AI tracks fuel consumption, engine performance, and tire pressure to ensure that vehicles are operating highly efficiently. Ai ensures that fleets operate in optimal conditions, reducing fuel waste and CO2 emissions caused by underperforming engines.

Internet of Things for sustainable operations. IoT is a network of interconnected devices, sensors, and software that continuously collect and share data. The adoption of IoT in logistics and freight transportation is not just improving efficiency and traceability. It's also a pathway to more eco-responsible operations, with a direct impact of reducing carbon footprints and energy consumption.

*Smart Fleet Management***.** IoT fleet management uses IoT technology, such as GPS trackers, telematics, and other sensors to collect data regarding vehicle health, fuel usage, road conditions, driver behavior, location, maintenance status, and more. With this data, companies gain more insight and become more efficient, save money and reduce their carbon footprints. It provides end-to-end visibility of the supply chain by tracking shipments, vehicles, and inventory in real time. This transparency helps businesses to reduce delays and ensure timely deliveries and this also helps in cargo safety by monitoring vehicles surrounding (Kuruvilla et al., 2020).

IoT-enabled warehouses. Warehouses consume high energy for lighting, cooling, heating, and machinery operations. IoT sensors help to save energy and support the environment by using smart systems to manage these operations efficiently. It keeps a record of how many people are in the warehouse, the temperature inside, and the weather outside. According to this information, it adjusts light and temperature to matches the weather and activity levels. That reduces the waste and makes energy use more eco-friendly (Kuruvilla et al., 2020).

IoT for reverse logistics and waste reduction. Reverse logistics is about handling return items in such a way that benefits both the environment and the economy. IoT is transforming the reverse logistics and waste reduction by dealing with the real-time tracking of returned products, optimizing recycling processes, and minimizing environmental impact (Liu et al., 2018). IoT-powered RFID tags and QR codes allow businesses to get information about where the product was purchased and guarantee the status and condition of a product while it is returned. This helps businesses to quickly make a decision that an item should be repaired, resold, or recycled, reducing unnecessary waste. Smart bins with IoT sensors automatically sort waste into recyclable categories, ensuring efficient disposal and promoting sustainability. IoT devices generate huge amounts of data that help businesses to analyse the patterns of product returns. So, they can plan better routes for transporting returned goods and decide in advance what to do with goods (Carissimi et al., 2024). As a result, businesses reduce unnecessary transportation, lower fuel consumption and cut down the carbon emissions, which makes reverse logistics more sustainable and cost effective.

Blockchain. The use of Blockchain in logistics can significantly enhance transparency, reduce errors, and improve transaction speed. Technology is transforming supply chains by enhancing transparency, traceability, and sustainability, ensuring that businesses adhere to ethical sourcing and environmental regulations (Aslam et al., 2024).

Verify sustainable sourcing. It is a secure digital record that tracks every step of a product's journey so that companies and consumers can be sure that products are made ethically. It keeps a permanent record of where raw materials come from, helping companies ensure they are sourced responsibly without harming the environment (Vladucu et al., 2024).

Reducing supply chain fraud. The records entered in the blockchain cannot be altered, so it helps to prevent fraud and waste in the supply chain by keeping fake products out and improving delivery efficiency (Idrissi et al., 2024). Since blockchain records cannot be altered, it ensures that only genuine and certified products enter the supply chain.

Smart contracts for environment compliance. Another benefit of blockchain is smart agreements that automatically enforce sustainability rules. These digital contracts ensure that suppliers meet environmental standards without needing constant monitoring (Vladucu et al., 2024).

In addition to the smart technologies detailed above, we can also mention Automation and Robotics for Sustainable Logistics. Logistics is becoming a more efficient and sustainable process, operations may reduce waste, energy use, due to automation and robotics. The deployment of autonomous vehicles in logistics holds significant environmental benefits. Autonomous vehicles are equipped with various sensors, such as LiDAR (light detection and ranging), radar, cameras, and GPS systems, which work together to perceive their surroundings. These technologies were able to detect any obstacle and follow traffic rules without needing a driver. It greatly benefits the environment by planning better routes and driving more efficiently, Drones are also used for last-mile deliveries, which leads to a reduction in fuel consumption and cutting down the emissions of greenhouse gases. Electric AVs are more environmentally friendly since they can run on renewable energy like solar and wind power (Nwankwo and Etukudo, 2024). For example, the Tesla Semi has extensive automation technologies that considerably boost safety and operational efficiency. It combines cutting-edge motor and brake controls with active safety features to provide exceptional traction and stability under all driving circumstances. The Tesla Semi is a revolutionary step toward sustainability in terms of the environment. Its all-electric design reduces the environmental impact of diesel trucks by doing away with exhaust emissions.

Automated systems like robotic sorting, automated storage and retrieval systems, and conveyors streamline operations, reducing energy consumption and waste. Automation supports sustainable practices by improving inventory management and reducing overstocking, which minimizes waste. A complete substitute for human picking is robotic arm picking. For accurate item handling it uses advanced sensors and a visual system. These robotic arms can adjust to different product forms and sizes by using machine learning and real-time data processing, increasing productivity and lowering operating expenses (Krishnamurthy et al., 2015).

The analysis of scientific literature revealed that the adoption of smart technologies helps to maintain the environment-friendly supply chain by reducing carbon emissions and optimizing energy usage. AI-based route optimization and IoT-enabled fleet management cut down the fuel usage, while electric vehicles and drones make last-mile deliveries faster and cleaner. AI-based inventory management and robotic automation increase warehouse productivity while reducing energy use and operating expenses. Blockchain supports material sourcing transparency, lowering supply chain fraud, and encouraging moral business conduct. Moreover, AI-powered predictive maintenance increases the life of machinery and automobiles, averting malfunctions and cutting down on resource waste. In addition to reducing waste, sustainable packaging solutions promote a circular economy in which materials are efficiently recycled and reused. By adopting these advanced technologies, companies gain a competitive advantage by meeting sustainability regulations, attracting eco-conscious consumers, and enhancing brand reputation. These developments not only help businesses but also build cleaner cities, a logistics sector that actively promotes international sustainability initiatives, and smarter cities.

Challenges in implementing smart sustainable logistics

Although adopting sustainable methods has many advantages, there are also a few drawbacks. The biggest hurdle to implementing smart sustainable logistics is the high upfront cost. Small and medium-sized enterprises cannot afford these technologies due to their limited budget. This cost not only includes purchasing of hardware and software but also training employees, upgrading infrastructure and maintaining advanced systems. Many companies rely on conventional supply chain systems that are not compatible with modern smart technologies. Upgrading these systems can be complex, time-consuming, and expensive, especially for large-scale logistics operations (Beredugo, 2024). Cybersecurity risks are

a major concern in logistics systems using IoT and blockchain, as they handle sensitive data that could be targeted by cyberattacks. To mitigate these threats, companies should utilize advanced security solutions, such as AI-powered tools for real-time threat detection and blockchain encryption, to ensure data safety (Kale, 2025). However, progress is also slowed by a lack of skilled workers in areas like AI, data analytics, and IoT management.

Prospects

Electric and hydrogen vehicles are essential for the transport industry's future due to their efficiency, minimal emissions, and cheaper operating costs. The popularity of Battery electric vehicles is growing. The future of electric and hydrogen-powered trucks looks bright, influenced by advancements, decreasing cost, and government support. Vehicles fueled by hydrogen, especially Fuel-Cell Electric vehicles, have a lot of potential for heavy-duty transportation because of their increased payload capacity, quicker refueling period, and longer range, which makes them perfect for freight and logistics operations (Shi, Y. et al. 2024). The declining cost of renewable energy is increasing interest in green hydrogen. Technological advancements, such as higher energy density and faster charging times, are expected to enhance their appeal. Companies like Volvo are already making high investments in zero-emission transportation. Volvo CE is investigating hydrogen fuel cell technology in addition to battery-electric solutions. The development and testing of its emission-free hydrogen fuel cell articulated hauler prototype, the Volvo HX04 (www.volvo.com), marks a significant turning point in this journey. As technology develops, smart warehouses will see 5G capabilities for quicker data transfer and real-time decision-making. Integrating blockchain technology for safe and transport inventory control. AI-powered self-learning warehouses that automatically adjust to shifting demand trends. AI robots will handle inventory, sorting, and delivery with minimal energy waste (Akaria, I. et al. 2024) . Businesses are using circular business models more and more to cut expenses, satisfy customer demands for sustainability, and adhere to legal requirements. With programs centred on recycling, renovation, and sustainable design, sectors including fashion, automotive, and construction are setting the standard. Companies will use AI and blockchain to optimize recycling, reuse, and waste reduction.

Conclusions

1. Smart technology such as AI, IoT, Blockchain, Automation, and robotics offers a game-changing chance to enhance sustainability in logistics and supply chain management. This study highlights how technologies optimize route planning, fleet management, warehouse operations, and transparency in supply chain management, leading to lower carbon emissions, energy consumption, and operational waste.
2. Even with these potential developments, these technologies face key challenges of high implementation costs, difficult integration, cybersecurity risks, and a lack of skilled workers. These barriers require careful planning, government incentives, and upskilling programs to smooth the transition to green logistics solutions.
3. Notwithstanding these challenges, logistics is moving toward a more intelligent, efficient, and greener ecosystem in the future. Companies that use these technologies will meet sustainability targets and see long-term operational and financial benefits. Businesses may create robust, environmentally friendly supply chains that support global sustainability initiatives while preserving competitiveness in a changing market by utilizing AI, IoT, blockchain, and robotics.

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