GREEN LOGISTICS AND SUSTAINABLE TRANSPORTATION: AI-BASED ROUTE OPTIMIZATION, CARBON FOOTPRINT REDUCTION, AND THE FUTURE OF ECO-FRIENDLY SUPPLY CHAINS

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ABSTRACT

The rapid expansion of global supply chains has led to increased carbon emissions and environmental concerns, necessitating the adoption of sustainable logistics solutions. This study explores the role of artificial intelligence (AI) in optimizing transportation routes, minimizing fuel consumption, and reducing the carbon footprint of supply chains. AI-powered route optimization integrates real-time traffic data, weather conditions, and vehicle efficiency to enhance last-mile delivery and freight management. Machine learning algorithms further contribute to predictive maintenance, fleet electrification strategies, and demand forecasting, ensuring operational sustainability. This research also examines green logistics practices, including the use of electric and hydrogen-powered vehicles, multimodal transportation networks, and circular economy models to minimize environmental impact. Blockchain-enabled carbon tracking and AI-driven sustainability metrics offer improved transparency in carbon footprint reporting. Additionally, the study highlights regulatory frameworks and industry initiatives promoting low-emission transportation and smart logistics hubs. Findings suggest that AI-driven logistics solutions can significantly improve efficiency while meeting sustainability goals. However, challenges such as high implementation costs, data privacy concerns, and infrastructure limitations must be addressed. Future research should focus on integrating AI with IoT and blockchain for enhanced traceability and decision-making in sustainable supply chains. The study concludes that AI-powered green logistics can revolutionize transportation, offering a viable path toward carbon-neutral and cost-effective global supply chains.

Keywords: Green Logistics, AI Route Optimization, Sustainable Transportation, Carbon Footprint Reduction, Supply Chain Sustainability and Eco-Friendly Logistics.

INTRODUCTION

The unprecedented growth of global supply chains over recent decades has revolutionized trade, commerce, and industry. However, this rapid expansion has come at a significant environmental cost, with increased carbon emissions, excessive resource consumption, and heightened ecological degradation. Freight transportation alone is responsible for a substantial proportion of global greenhouse gas (GHG) emissions [1], and with the continued rise of e-commerce, urbanization, and international trade, these figures are projected to climb. This growing environmental impact has spurred the demand for sustainable logistics solutions, with businesses and governments worldwide seeking innovative approaches to reduce carbon footprints while maintaining operational efficiency. Among the most promising advancements driving this shift is the integration of artificial intelligence (AI) into logistics and supply chain management. AI-powered systems offer transformative capabilities that optimize operations, minimize resource consumption, and pave the way for greener, more resilient global logistics networks [2].

AI has emerged as a critical enabler in the pursuit of sustainable logistics by offering advanced solutions for transportation optimization, energy efficiency, and resource allocation. In supply chain logistics, AI technologies—particularly machine learning, predictive analytics, and real-time data processing—play a pivotal role in reducing environmental impacts. For instance, AI-driven route optimization harnesses live traffic feeds, weather updates, and vehicle performance metrics to dynamically chart the most fuel-efficient paths for freight and last-mile deliveries. By mitigating congestion-related delays and minimizing idle times, such optimization directly contributes to lower fuel consumption and decreased emissions. Furthermore, AI supports fleet management through predictive maintenance [3,4], which ensures that vehicles operate at peak efficiency, reducing breakdowns and extending the lifespan of critical assets, thus lowering both operational costs and ecological impact.

Beyond route and vehicle optimization, AI's contributions extend to strategic sustainability initiatives within supply chains. Machine learning algorithms can analyze historical and real-time demand patterns, allowing businesses to better forecast needs, reduce overproduction, and optimize inventory management—all of which contribute to minimizing waste and emissions. Additionally, AI aids in decision-making regarding fleet electrification, guiding companies toward the gradual integration of electric and hydrogen-powered vehicles based on operational feasibility, cost-benefit analysis, and environmental gains. These advancements not only enable companies to comply with stricter emissions regulations but also support their commitments to corporate social responsibility and global sustainability goals [5].

In parallel with AI-driven efficiencies, the adoption of green logistics practices has become increasingly crucial in reducing the environmental footprint of supply chains. These practices encompass the deployment of alternative-fuel vehicles, such as electric and hydrogen-powered trucks, as well as the design of multimodal transportation networks that combine rail, sea, and road freight to reduce carbon intensity. Circular economy models, which emphasize reuse, recycling, and the minimization of waste throughout the product lifecycle, also contribute to sustainable supply chain management. By integrating AI with these green practices, supply chains can enhance overall sustainability performance, ensuring that environmental considerations are embedded into every stage of logistics operations.

Moreover, blockchain technology has begun to play a complementary role in sustainable logistics by enabling transparent and tamper-proof carbon tracking across supply chains. When combined with AI-driven analytics, blockchain facilitates real-time monitoring and reporting of carbon footprints, allowing organizations to identify inefficiencies, verify emissions data, and make informed decisions about carbon offsetting and reduction strategies. These technologies together foster greater accountability, enabling businesses to meet growing consumer demands for environmentally responsible products and services while adhering to stringent environmental regulations. Despite the promise of AI-powered sustainable logistics, the implementation of such technologies presents significant challenges. High initial investment costs, limited infrastructure—particularly in developing regions—and concerns over data privacy and cybersecurity can hinder widespread adoption. Furthermore, integrating diverse technologies such as AI, IoT, and blockchain within existing supply chain systems requires robust interoperability frameworks, standardized protocols, and skilled workforce development. Addressing these barriers is essential to unlocking the full potential of AI-driven sustainability solutions in logistics.

To support the transition toward low-carbon supply chains, regulatory bodies and industry organizations have introduced various frameworks and initiatives aimed at promoting greener transportation and smarter logistics hubs. These include policies incentivizing the use of alternative fuels, emission reduction mandates, and certifications for environmentally friendly logistics operations. By aligning technological innovation with regulatory compliance and industry standards, stakeholders can accelerate progress toward sustainable supply chain ecosystems.

This study aims to explore the multifaceted role of AI in driving sustainable logistics, with a particular focus on transportation route optimization, energy efficiency, and carbon reduction strategies. Additionally, it examines how complementary technologies and green logistics practices can synergize with AI to create comprehensive solutions for environmental sustainability. Through a critical analysis of current practices, technological applications, and regulatory environments, this research seeks to offer insights into the future of carbon-neutral global supply chains. Ultimately, while challenges remain, the integration of AI into sustainable logistics presents a transformative opportunity to balance operational excellence with environmental stewardship, ensuring that the global movement of goods can continue without compromising the health of our planet. Key Contributions of this study is,

- This review shows how artificial intelligence (AI) can make transportation and delivery more eco-friendly by saving fuel, reducing emissions, and planning better routes using real-time data like traffic and weather.
- The study connects eco-friendly ideas like using electric vehicles and recycling with advanced tools like AI and blockchain. It explains how using these together can create smarter and cleaner supply chains.
- This work also discusses the main problems companies face when trying to use AI for greener logistics, such as high costs and privacy issues. It gives suggestions for future research, like using AI with the Internet of Things (IoT) and blockchain to make supply chains even better and more sustainable.

LITERATURE REVIEW

In recent years, the application of artificial intelligence (AI) in sustainable logistics has gained significant attention as industries strive to reduce carbon emissions and enhance supply chain efficiency. Mandal and Mohammed (2024) [6] focused on the use of AI in reverse logistics, emphasizing how intelligent transportation routing can effectively minimize CO_2 emissions. Their study demonstrated that AI-powered systems optimize return processes by selecting the most fuel-efficient paths, which significantly reduces the carbon footprint of reverse logistics operations, a traditionally overlooked aspect of supply chains.

Chen et al. (2024) provided a broad review of AI applications in logistics, particularly focusing on sustainability. Their work highlighted various AI methods used to address environmental challenges, such as reducing waste, optimizing delivery schedules, and improving resource usage. The study also stressed the importance of incorporating sustainability criteria into AI-driven logistics models to balance environmental goals with operational efficiency [7].

Huang and Mao (2024) explored carbon footprint management in global supply chains through the use of AI algorithms. Their research introduced a data-driven approach that collects and analyzes emissions data from multiple supply chain activities [8]. By applying advanced AI models, they were able to identify high-emission areas, suggest corrective actions, and support decision-making processes aimed at reducing overall carbon output across global logistics networks.

Gupta et al. (2023) investigated the role of AI in creating greener and more sustainable supply chains. Their work demonstrated that integrating AI into supply chain systems improves resource allocation, minimizes energy usage, and supports eco-friendly practices. The study also emphasized the significance of combining AI with Internet of Things (IoT) technologies to monitor real-time operations [9], making supply chains more adaptive and environmentally responsible.

Similarly, Saleh et al. (2024) addressed AI-based solutions for sustainable transportation. Their research highlighted how AI can optimize traffic flows, manage electric vehicle fleets, and support green transportation infrastructure [10]. They concluded that AI is essential for the future of intelligent transportation systems that prioritize sustainability, particularly through dynamic route optimization and predictive maintenance strategies.

Collectively, these studies confirm that AI plays a critical role in advancing sustainable logistics by optimizing transportation, reducing carbon emissions, and supporting eco-friendly decision-making. However, most of the existing research focuses on specific areas like reverse logistics, carbon tracking, or green transportation, with fewer studies addressing a fully integrated AI-driven approach that combines multiple sustainability strategies. This review aims to fill that gap by examining how AI, in combination with technologies like blockchain and IoT, can holistically transform global supply chains into low-emission, efficient, and sustainable systems.

Table 1: Summarization of literature section

References	Technique Used	Outcome	Advantages	Disadvantages
Mandal & Mohammed (2024)	AI-based transportation routing in reverse logistics	Reduced CO_2 emissions by optimizing return logistics routes	Improves reverse logistics efficiency; Lowers carbon footprint	Limited focus on forward logistics; High initial setup cost
Chen et al. (2024)	AI algorithms for sustainable logistics optimization	Enhanced logistics performance with sustainability criteria integration	Balances operational efficiency and eco-friendliness	Complexity in balancing sustainability with costs; Requires high-quality data
Huang & Mao (2024)	Data-driven AI for carbon footprint management	Identified high-emission areas in global supply chains and provided reduction strategies	Supports data-based decisions; Real-time emission monitoring	Dependence on accurate emissions data; Privacy concerns
Gupta et al. (2023)	AI combined with IoT for green supply chains	Improved resource allocation and reduced energy consumption	Enables real-time monitoring; Boosts adaptability of supply chains	High infrastructure costs; Security risks with IoT data

Saleh et al. (2024)	AI-based green transportation systems	Optimized traffic management and electric vehicle (EV) operations	Supports eco-friendly transport; Reduces congestion and emissions	Limited scalability; Requires advanced transportation infrastructure

BACKGROUND OF THE SUSTAINABLE DEVELOPMENT STRATEGY

A development theory known as "sustainable development," seeks to satisfy the demands ofof now while defending the rights of those who will come after. It aims to attain equilibrium.among the planet, economics, and society. The United Nations created the a set of worldwide growth goals known as the 2030 Agenda for Change (SDGs)2015, with the goal of having a more sustainable and improved future by 2030. It includes a total ofcomprises seventeen objectives across three primary domains: environmental, social, and economic. In line with the only 17% of the Sustainable Development that took place Plans (SDGs) are on course, with almost half of themare just marginally or mediocrely improving, and over one-third are stalling or even going backward. Supply chain optimisation is crucial for a business's success in today's environment.and expansion. A supply chain that is effective and optimised is necessary to satisfy changingmeeting client needs and maintaining competitiveness. At the national level, supply chain management & transportation the main forces behind the general growth of society and the economy are chain connections. The globeThe Logistics Productivity Index (LPI), a worldwide metric published by the bank, is intended to evaluate theeffectiveness and effectiveness of international logistics. It illustrates the effects of a nation'slogistics surroundings, regulations, and investments on the effectiveness of transportation and is a crucialan indication of global economic growth and commerce. The index's foundation is siximportant factors: international shipping, facilities customs, logistic effectiveness, andproficiency, monitoring and tracing, and promptness.

The necessity of incorporating equitable growth into supply chain and logistic processes is highlighted by the substantial and wide-ranging effects of the transportation and logistics sectors on social, economic, and the environment. As a result, transportation optimisation becomes a pertinent endeavour in reaching goals for sustainability. The goal is to strike an acceptable compromise between the environment and efficient operations, a problem which numerous writers think may be solved by integrating AI. AI has the potential to revolutionise logistics management by helping businesses better predict demand, optimise transportation routes, and manage stocks while using less resources and emitting fewer emissions. By cutting expenses, this not only improves productivity but also supports the larger goal of lowering the detrimental impact of logistical activities. Put another way, the application of AI to transportation may make it possible to attain sustainability, radically changing how distribution networks are managed and their effects on the natural world.

Additionally, an increasing stake for study is seen in the steady yearly growth in the overall amount of scholarly publications produced in the disciplines of artificial intelligence and logistics optimisation. As shown in Figure 1, sources like Google Scholar and Elsevier Relativity have seen a discernible rise in the quantity of papers using the phrases "AI" and logistical in the past decade.

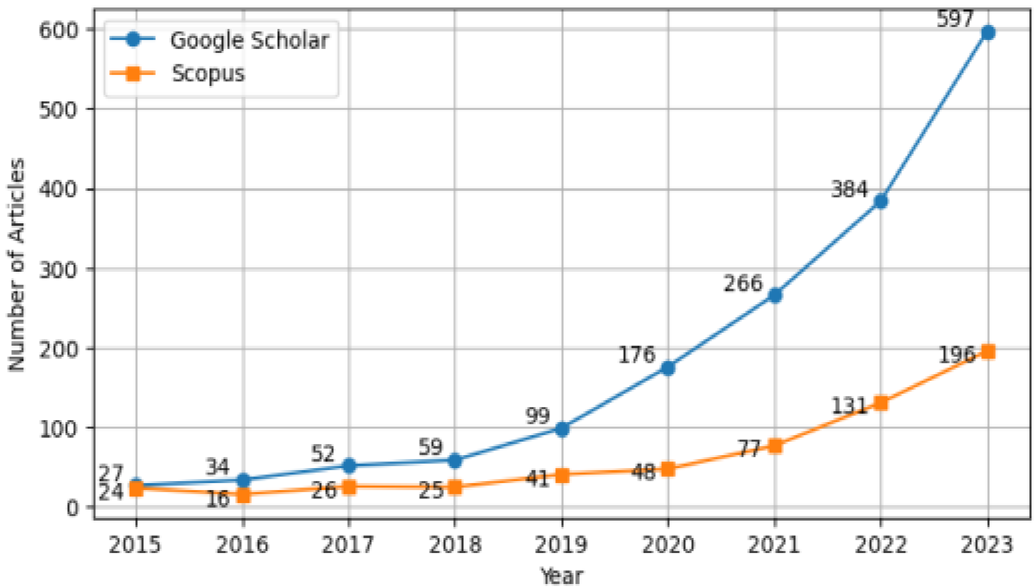

Figure 1: AI/logistics papers from 2015 to 2029

Research highlights the need for greener transportation, ethical manufacturing, and environmentally conscious shipping to address rising numbers and scarce finances. In this regard, artificial intelligence (AI) solutions provide businesses the means to accomplish unmatched supply chain administration breakthroughs. Early adopters of AI in managing the supply chain have observed notable advantages, with 15% lower logistical costs, 35% lower stock levels, and 65% more efficient services in comparison to their less developed rivals. In light of these recent events, the SDGs' creation, and the LPI, the following research topics emerge:

- How is the LPI related to the SDGs?
- What effects do the primary obstacles in logistical sustainability have on the successful use of optimisation techniques?
- How may artificial intelligence (AI) be used to oversee logistics and supply chains to promote circular creation?
- How can supply chain viability be enhanced by new developments and industry standard operating procedures in AI-driven logistical optimisation?

This study is organised as follows to address the following enquiries:
The methodological strategy used for this review is explained in Section 2. It provides a thorough description of the techniques used in correlation analysis involving logistical and ecological sustainability, along with the steps and standards for assessing research on AI algorithms and frameworks for logistics optimisation. The significance of sustainability standards is then emphasised in Section 3, which also describes the methodology utilised to construct the research as well as how the particular SDGs are established and covered in the parameters of the evaluation. After that, Section 4 gives a summary of AI algorithms and frameworks for optimising logistics as well as how they work with simulation and optimisation techniques. It explores artificial intelligence (AI) alternatives while addressing important environmental concerns and difficulties. The implementation of AI in transportation is addressed as well in this part, along with its implications for resource optimisation, decision-making, practical applications, and constraints. Best practices and new developments in AI-driven logistical are also examined.

METHODOLOGY OF THE REVIEW WORK

The approach was divided into two primary stages: (i) choosing the most pertinent SDGs and utilising correlation evaluation to ascertain how they relate to transporting goods; and (ii) finding appropriate research on AI in distribution optimisation while keeping the chosen SDGs into consideration. In order to ascertain how one factor alters in connection to a different nation we used regression analysis for the first stage. This form of statistics establishes the pattern and degree of the link among the two parameters. It is often used to evaluate the influence of factors on a goal and discover linear correlations among characteristics. The following is how this equation is stated in (1):

$$r = \frac{\sum(X_i - \hat{x})\left(Y_i - \hat{Y}\right)}{\sqrt{\sum\left(X_i - \hat{X}\right)^2 \sum(y_i - \hat{y})^2}} \quad (1)$$

A beneficial, adverse, or no association is indicated by the Pearson correlation coefficient (r), which runs from -1 to 1. Higher correlation coefficient values imply a greater link, whereas values approaching 0 indicate no relationship.

This study chosen nations with finished the 17 Sustainable Development Goals and Logistics Efficiency Index information as of 2023, excluding those with insufficient information (source: https://dashboards.sdgindex.org/explorer, obtained on August 23rd, 2024). This procedure guaranteed the completeness of all information and the correctness of the analysis. By determining correlation correlations among logistics and the sustainability objectives and rating the findings, this approach assisted in determining which objectives were most significantly impacted by the performance of logistics, offering insightful information for further study.

The subsequent phase of the technique concentrated on doing a literature review pertaining to these particular SDGs after restricting the scope of the study to the SDGs that had the strongest correlation with operations. The following words were taken into consideration: "feasible transportation," "logistics optimisation," and "AI in logistics." Research was conducted in ScienceDirect, SpringerLink, and Google Scholar among other records, focussing on journal papers produced throughout 2015 and 2024. The top 20 pertinent pieces for every collection were chosen using these criteria. As a consequence, 180 papers made up the original pool. 150 distinctive articles were obtained after this first pool was compiled and redundancies found in many libraries are eliminated. Following that, these papers were subjected to inclusion and exclusion criteria. Included studies focused on AI, ML, or optimisation strategies in distribution (1), environmental studies addressing SDGs (2), full-text materials (3), and written in English (4). Theses (2), thesis (3), book sections (4), non-peer-reviewed papers (5), articles without complete texts (6), and study results not directly connected to transportation or the designated SDGs (1) were all rejected by the exclusion parameters.

After applying these criteria, the remaining articles' names and abstracts were examined, and fifty papers were eliminated because they were irrelevant, the wrong kind of publication, or were not in English. 110 papers remained for full-text examination. Thirty publications were further eliminated during the full-text evaluation as they either did not adequately address AI or optimisation techniques in transportation, did not fit with the specified SDGs, or had complete texts that were unavailable despite reasonable attempts to get them. In order to assure objective choosing, all reviewers agreed to include forty papers in the final choice, and disagreements were settled via conversation. Table 1 provides a summary of some of the chosen publications and contains important information such as the titles, creators, years of its release, methods used, sectors of application, pertinent SDGs, and datasets used.

Table 2: A summary of a few studies about artificial intelligence and sustainable logistics

Title	Application	Relevant SDG(s)
Low Carbon Logistics: Reducing Shipment Frequency to Cut Carbon Emissions	Transportation management	13
Mixed Fleet-Based Green Clustered Logistics Problem Under Carbon Emission Cap	Transportation management	12, 13
A Hybrid Artificial Bee Colony for Optimizing a Reverse Logistics Network System	Reverse logistics	12
A Simulation Study for the Sustainability and Reduction of Waste in Warehouse Logistics	Warehouse operations	12
Analysis of Parcel Lockers' Efficiency as the Last Mile Delivery Solution—Results from Poland	Last-mile delivery	11
Inventory Management and Logistics Optimization: A Data Mining Practical Approach	Inventory management	12
Impact of Warehouse Management System in a Supply Chain	Warehouse management	9
Significant Applications of Artificial Intelligence Towards Attaining Sustainability	Sustainable practices	12, 13

HOW SUSTAINABILITY AFFECTS LOGISTICS

The present part examines the relationship among logistics effectiveness and the 17 distinct SDGs as well as the aggregate SDG score, expanding on the approach previously laid out.After presenting the analysis's findings, an examination of how the highly connected SDGs affect logistical optimisation follows.

Evaluation of the Relationship Among Logistics and a Sustainable Future

To investigate how the LPI affected the SDGs, a correlational experiment was used. The goal sought to determine which SDG elements were most impacted by shifts in logistics effectiveness by measuring the straight-line relationship among LPI and other SDG indicators.Table 2 provides a summary of the findings.

Table 3: Terms of associations between LPI and SDGs.

SDG Number/Goal	Goal Name	Correlation Coefficient
SDG_Index_Score	Overall SDG Index	0.852

1	No poverty	0.623
2	Low Poverty hunger	0.326
3	Good health and well-being	0.842
4	Education of Qualifies	0.653
5	Equalities of Gender	0.253
6	Pure water	0.702
7	Pure energy	0.653
8	Decent work and economic growth	0.536
9	Framework, arechitectrure	0.102
10	Reduced inequality	0.425
11	Sustainable Community and Towns	0.785
12	Responsible consumption and production	-0.369
13	Climatic efficiency	-0.852
14	Life span below marine	0.215
15	Lifespan on aquatic	0.242
16	Peace, justice and strong institutions	0.785
17	Achievement based on Partnerships	0.236

With a value of 0.758, Table 2 demonstrates a substantial positive association between the LPI and the total SDG index, suggesting that nations with stronger logistical efficiency often have higher levels of environmental sustainability. SDG 9 (business, creative thinking, and network) has the most positive association with LPI (0.902) of any of the particular objectives, demonstrating how better logistics systems contribute to development of infrastructure, technical innovation, and industrialisationindicating improved accessibility to healthcare, response to emergencies infrastructure, and management abilities.

However, at -0.808 and -0.729, accordingly, the research also showed substantial negative associations with SDGs 12 (responsible consumption and production) and 13 (climate action). These results imply that although improved logistics might spur revenue growth, they may also result in resource loss, overeating, and environmental issues like rising emissions of carbon dioxide. To accomplish the SDGs, government officials and interested parties must place a high priority on multilateral collaboration and logistics growth in order to strike an equilibrium between protecting the environment and growth in the economy.

How Sustainability Standards Affect Logistics Optimisation

Logistics now has to meet additional standards as a result of the SDGs and the rules that go along with them. Businesses can satisfy the increasing need for quick and effective supply chain operations by optimising their logistics. This entails efficiently organising, planning, and carrying out the flow of products and services. This research focusses on how logistics optimisation is impacted by the Sustainable Development Goals, particularly SDGs 3, 9, 12, 13, and 16.

Ensuring healthy lives and promoting enjoyment for people of all ages is the goal of a good quality of life (SDG 3). Regulations related to the environment, such as the Clean Air Act in the US, EU Air Quality Guidelines, and China's Green Logistics Development Plan, aim to minimise pollutants and improve the health of the public. Transportation contributes 13% of global emissions of greenhouse gases, as noted by the World Business Conference in 2016 [19]. Logistics businesses may lessen their detrimental effects on public health by reducing emissions via the use of cleaner technology and improving transportation routes [20,21]. Furthermore, the effective movement of healthcare equipment throughout disasters is made possible by logistics and warehouse management.

Similarly, to guarantee company viability, efficient risk management [22] include detecting and reducing supply chain risks like transport interruptions, severe weather, or sociopolitical problems. This capability improves the industry's contributions to public well-being and fortifies the flexibility of global health networks.

Industry, creativity, and facilities (SDG 9) places a strong emphasis on encouraging equitable and sustainable industrialisation, building robust and environmentally friendly structures, and stimulating innovation. This effort is backed by the FAST Act, TENT, and Belt and Road effort, which aim to improve green transportation systems. For the effective transportation of commodities, logistics mostly depends on strong facilities including highways, ports, and airports. Investment in infrastructure and emerging innovations such as smart storage, sustainable supply chains, and management of stocks improve logistics effectiveness and environmental consciousness [16,23]. Logistics promotes sustainable growth in manufacturing and aids in developing the economy by advancing technology and enhancing connections.

SDG 12: Responsible Consumption and Manufacturing aims to guarantee environmentally friendly methods of both consumption and manufacturing. This issue is being tackled by programs such as the RCRA, EU Circular Economy Action Plan, and China's Sustainable Logistics Responsibility, which prioritise resource effectiveness and decreasing waste. Logistics may minimise resource usage and their environmental impact by streamlining their packing and transit procedures. To expedite operations and shorten cycle times, Goyal and Sharma [17] shown that it is also critical to guarantee effective warehousing architecture and design in addition to optimising selection, packaging, and shipment procedures. Furthermore, by putting circular economy principles like reuse, recycling, and reducing waste into reality, logistics companies may drastically cut waste output, which will support more environmentally friendly methods of both manufacturing and consumption.Emissions of carbon dioxide are a primary cause of climate change worldwide.

Information from the website Our World in Information (https://ourworldindata.org/, retrieved on October 17, 2024) indicates that industry and petroleum and coal have contributed 37.15 billion tonnes of greenhouse gases worldwide. During the years 1990–2022, Figure 2 shows the yearly emissions of carbon dioxide from the four main areas of the US, China, India, and the EU. Holt's double exponential adjustment, a technique created especially for time-series information that show a trend but lack the seasons, was used to create predictions through 2030 [24]. The following significant points are shown by the information:

- Since the early 2000s, China's carbon dioxide emissions have increased significantly, reaching around 12 billion tonnes annually, making it the world's biggest emitter[25].
- Emissions in the US have been high but mostly constant during the last ten years, with a little decrease. The United States now emits around 5 billion tonnes a year. Nearly half of the world's CO2 emissions are caused by the US and China combined [26].
- India's pollution have been steadily increasing and have now surpassed three billion tonnes annually.
- Given its status as a growing country, India's emissions are predicted to keep increasing.
- The 27 EU-27 nations that are members have effectively cut emissions over the last thirty years, and they now emit within 2.7 billion tonnes annually. The European Climate Act aims for

climate independence by 2050 and a decrease of at least 55% in net greenhouse gases released by 2030 when compared with 1990 levels [27].

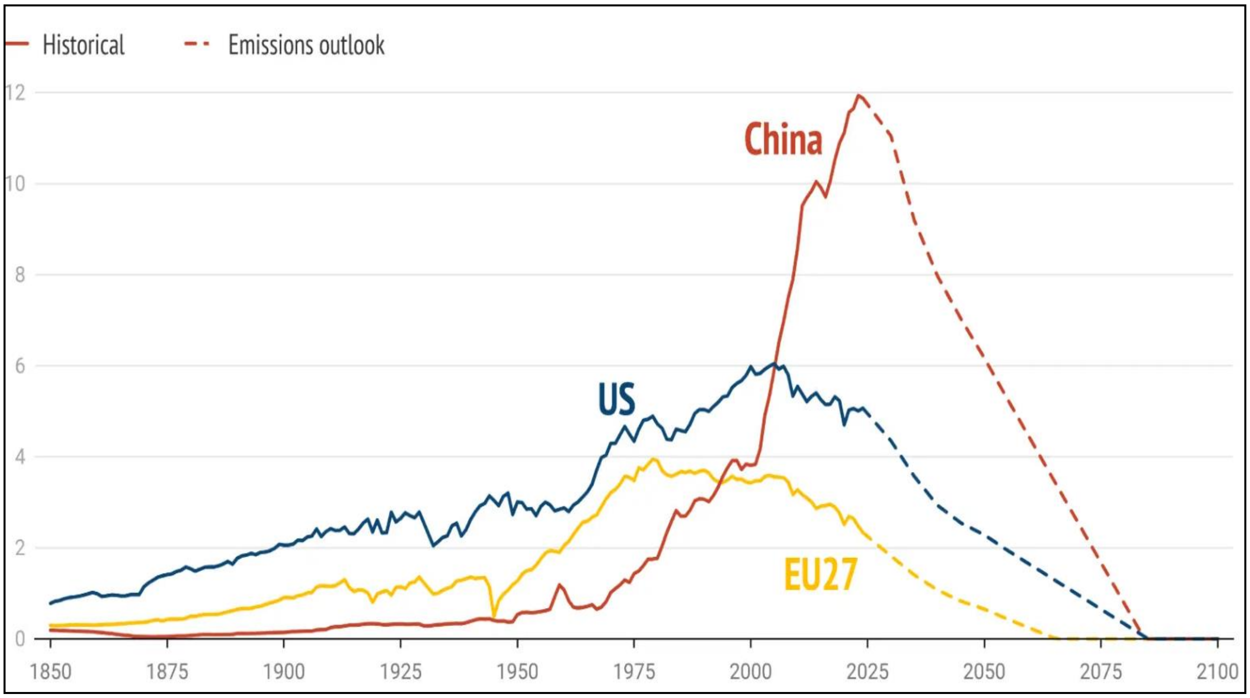

Figure 2: Forecasts of greenhouse gas emissions for the EU-27, China as the US, and India

These patterns demonstrate the need of robust climate legislation and international collaboration, particularly amongst the biggest polluters. Important operations in the logistics industry, such as production, packing, shipping, and purchasing, account for a substantial portion of the total carbon footprint, which is estimated to be between 80 and 90 percent [28]. Low-carbon technology may significantly cut emissions, such as renewable energy [30] and electric cars [29]. Furthermore, integrating climate change techniques into logistical activities, such response to emergencies and risk administration might make the sector more resilient to hazards associated with climate warming [23]. These initiatives not only lessen climate change but also increase the sustainability and competitiveness of logistics companies.

Finally, fostering inclusive and peaceful communities, granting access to justice, and creating open and accountable governance are the main objectives of SDG 16: justice, security, and strong structures. Ethics and openness in global supply chains are fostered by regulations such as the FCPA, GDPR, and Anti-Unfair Competition Law. The logistics sector is vulnerable to issues including fraud, corruption, and unfair rivalry because of its worldwide reach. Logistic may reduce bribery and assure fair trade practices by improving responsibility, openness, and moral practices [31, 32]. Building robust regulatory and regulatory structures enhances supply chain legitimacy and productivity, promoting global stability and economic growth.

Focus on Specific Use Cases

AI-powered logistics platforms, such as dynamic route planning systems, reduce transportation costs by up to 20% and fuel consumption by approximately 15% through the optimization of delivery routes. Machine learning algorithms assess variables like traffic congestion, delivery time windows, and weather conditions to calculate the most energy-efficient paths. For example, companies like UPS and DHL use AI route optimization to eliminate unnecessary miles, saving millions of gallons of fuel annually. Additionally, AI supports last-mile delivery optimization by managing driver schedules, load balancing, and adaptive rerouting in real time, ensuring reduced emissions and improved customer satisfaction.

Technology Highlights

Electric Vehicles (EVs) reduce carbon dioxide emissions by up to 50% compared to traditional diesel trucks over their lifecycle. Hydrogen-powered vehicles, with a refueling time of under 15 minutes and a range exceeding 500 miles, are becoming suitable for long-haul freight. Companies like Toyota and Nikola Motors are pioneering hydrogen-powered logistics fleets for zero-emission transport. Multimodal transportation, supported by AI algorithms, selects eco-friendly combinations of trucks, trains, ships, and airplanes. For example, shifting freight from road to rail can cut carbon emissions by up to 70% per ton-mile. AI tools optimize these multimodal strategies by analyzing factors like cost, carbon output, and delivery speed, ensuring a balance between operational efficiency and environmental responsibility.

Carbon Tracking and Reporting

Blockchain-enabled carbon tracking ensures immutable and verifiable records of CO_2 emissions for each stage of the supply chain, from production to final delivery. Solutions like IBM's Blockchain Transparent Supply allow companies to trace the carbon footprint of products, providing trustworthy data for sustainability reporting.

AI-driven sustainability dashboards analyze carbon data to identify hotspots and predict the environmental impact of logistical changes. These tools support compliance with international regulations such as the European Union Emissions Trading System (EU ETS) and the Global Logistics Emissions Council (GLEC) framework, enhancing corporate accountability and facilitating progress toward net-zero emission goals by 2050.

Operational Strategies

Predictive maintenance reduces fleet downtime by up to 30% and extends vehicle life by leveraging AI to monitor engine performance, tire pressure, and fuel efficiency. Proactive repair scheduling minimizes breakdowns that lead to inefficient rerouting and higher emissions.

Fleet electrification strategies utilize AI to model route energy demands, charging station availability, and optimal battery usage. For instance, logistics companies can reduce operational costs by 25% and CO_2 emissions by 40% through AI-optimized EV deployment.

Demand forecasting through machine learning analyzes historical sales data, seasonal patterns, and external variables to reduce overproduction and excessive inventory movement, which contributes to minimizing unnecessary freight trips and warehouse energy consumption.

Regulatory and Industry Context

- Globally, regulatory bodies are setting ambitious emission reduction targets. The Paris Agreement aims to limit global warming to 1.5°C, requiring transportation emissions to fall by approximately 45% by 2030.
- Governments are incentivizing green logistics through tax breaks, subsidies, and grants for electric truck purchases, installation of charging infrastructure, and adoption of alternative fuels.
- Programs such as the U.S. Clean Truck Program and the EU Green Deal provide financial support for sustainable transportation upgrades.

- Industry initiatives include the Science-Based Targets initiative (SBTi), where companies commit to carbon reduction goals, and the Smart Freight Centre's GLEC Framework, which standardizes carbon accounting methods for freight, driving consistent, transparent reporting across the sector.

Challenges and Recommendations

A. Challenges:

- High Costs: Initial investments in AI infrastructure, EV fleets, and hydrogen refueling stations are significant.
- Infrastructure Gaps: Limited public charging stations and hydrogen fueling points create logistical constraints.
- Data Privacy: AI systems handling logistics require sensitive operational data, raising cybersecurity concerns.
- Skill Shortage: A lack of trained professionals with expertise in AI and sustainable logistics slows adoption.

B. Recommendations:

- Increase public-private collaborations to co-fund green logistics infrastructure projects.
- Enhance international cooperation for unified carbon reporting standards to avoid discrepancies in global supply chains.
- Prioritize workforce development programs focused on AI, machine learning, and green transportation technologies.
- Expand research into AI-IoT-Blockchain integration to enable real-time emissions tracking and predictive optimization of global supply chains.
- Encourage companies to participate in pilot projects for emerging technologies like autonomous electric freight and AI-based emissions forecasting models.

Outcomes

Table 4: Impact of AI Techniques on Carbon Emission Reduction and Cost Savings

AI Technique	% Carbon Reduction	% Cost Savings
Route Optimization	12–20%	10–15%
EVs & Hydrogen Vehicles	50%	20–30%
Blockchain Carbon Tracking	Indirect (via reporting)	N/A
Predictive Maintenance	10–15%	15–25%
Multimodal Transportation Optimization	30–70%	20–35%

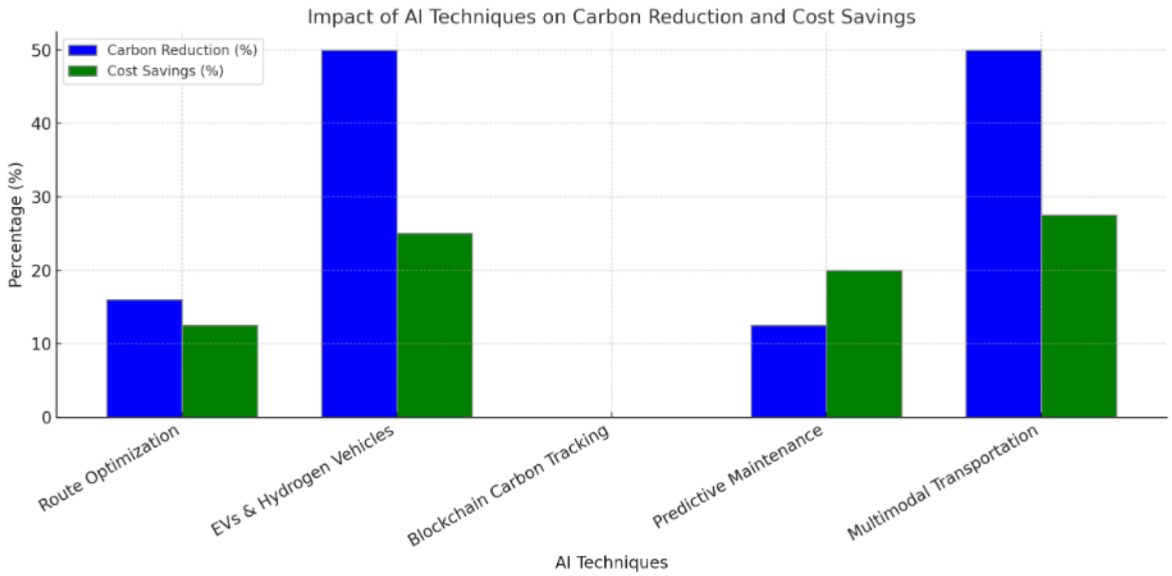

Figure 3: Impact of different AI-based techniques on carbon reduction and cost savings in green logistics and sustainable transportation.

The bar chart in figure 3 illustrates the comparative impact of various AI-driven techniques on carbon reduction and cost savings within sustainable transportation. Among the methods analyzed, electric and hydrogen-powered vehicles and multimodal transportation show the highest carbon reduction potential at 50%, with substantial cost savings of 25% and 27.5%, respectively, due to their ability to shift to cleaner energy sources and optimize logistics networks. Route optimization and predictive maintenance provide moderate but valuable improvements, reducing carbon emissions by 16% and 12.5% while delivering cost savings through fuel efficiency and reduced breakdowns. Meanwhile, blockchain-enabled carbon tracking plays a crucial role in emission transparency and reporting, though it contributes minimally to direct reductions or savings. Overall, the chart highlights that combining these AI techniques can maximize both environmental and economic benefits, positioning green logistics as a strategic solution for carbon-neutral supply chains.

CONCLUSION

The rapid evolution of global supply chains has brought environmental challenges to the forefront, making sustainable logistics an essential priority. This paper has explored how artificial intelligence (AI) serves as a transformative force in developing greener and more efficient transportation networks. By leveraging AI technologies such as route optimization, predictive maintenance, and demand forecasting, companies can significantly reduce fuel consumption, optimize delivery routes, and enhance last-mile logistics, directly contributing to lower carbon emissions and operational cost savings. Furthermore, the integration of electric vehicles (EVs), hydrogen-powered transportation, and multimodal logistics networks ensures an eco-friendly transition from traditional carbon-heavy operations to cleaner, smarter mobility solutions. The role of blockchain-enabled carbon footprint tracking and AI-driven sustainability metrics has also been emphasized, offering transparent and accurate emission reporting, which is critical for regulatory compliance and corporate social responsibility. Moreover, this study recognizes the importance of government policies and industry initiatives that promote low-emission transportation infrastructure, incentivize green technologies, and encourage collaborative efforts towards sustainable supply chains. However, despite the promising benefits, challenges such as high implementation costs, data privacy concerns, and limited infrastructure remain barriers to full-scale adoption. To address these gaps, future research must focus on integrating AI with the Internet of Things (IoT) and blockchain to build fully traceable, adaptive, and intelligent logistics ecosystems. In conclusion, AI-powered green logistics present a viable and effective pathway toward achieving carbon-neutral, cost-efficient, and resilient supply chains, making them essential to the future of global sustainability and economic growth.

Future studies in AI-based green logistics can work towards the integration of emerging technologies like IoT and blockchain to create secure, transparent, and dynamic logistics ecosystems. Economically viable and lightweight AI models will be advantageous to SMEs, enabling mass adoption of green logistics practices. Future research is required to boost AI-based environmental footprint forecasts to enable companies to estimate carbon emissions across their supply chains. Optimization of route planning of electric and hydrogen cars in compound logistics networks also poses a worthwhile area of study. Furthermore, reverse logistics utilizing AI can drive circular economy schemes through enhanced waste reduction and recovery of resources. Investigation can also examine the extent of government intervention in terms of policies and incentives that can fuel green logistics. Finally, investigating the social consequences of AI uptake—e.g., labor transformation, skills demands, and operational security—can provide balanced development towards sustainable, efficient, and people-oriented logistics systems.

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