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Carbon Footprint Tracking in Logistics System: A Survey of AI-Based Emission Monitoring Approaches

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Abstract: The logistics and transportation industry is one of the leading contributors to global carbon dioxide (CO_2) emissions. With the rapid growth of e-commerce and supply chain operations, accurately monitoring and reducing carbon footprints in logistics has become a critical environmental and operational challenge. This paper presents a survey of existing research on AI-driven carbon emission monitoring, route optimization, green logistics, and machine learning-based prediction systems. Six key studies are analyzed and compared across dimensions such as methodology, dataset, emission parameters, AI models, and limitations. Based on this survey, we propose a comprehensive web-based Carbon Footprint Tracking System for logistics operations that integrates machine learning-based emission prediction, AI-powered route optimization, shipment-wise carbon tracking, and a centralized analytics dashboard. The proposed system aims to address key gaps in existing approaches by combining real-time tracking, future emission forecasting, and actionable carbon reduction recommendations in a unified platform.

Keywords: Carbon Footprint, Logistics Emissions, Green Logistics, Route Optimization, Machine Learning, CO_2 Prediction, Sustainable Transportation, Emission Tracking, Artificial Intelligence, Smart Logistics

I. INTRODUCTION

The transportation and logistics sector contributes approximately 24% of global CO_2 emissions from fuel combustion, with road freight alone accounting for nearly 40% of that share. As global supply chains expand and e-commerce volumes surge, the environmental burden of delivery operations has grown substantially. Despite increasing pressure from regulators and consumers for sustainable practices, most logistics operations continue to lack systematic tools for monitoring and managing their carbon output at the shipment level.

Traditional emission estimation methods rely on static emission factors and manual calculations, offering limited accuracy and no real-time adaptability. Modern AI and machine learning (ML) techniques have shown significant promise in addressing these limitations by enabling dynamic prediction models that account for variables such as vehicle type, fuel consumption, traffic density, load weight, weather conditions, and route characteristics.

Several recent research efforts have explored AI-based approaches to green logistics and emission management. However, these works tend to address individual aspects of the problem in isolation—some focusing only on route optimization, others on emission prediction, and yet others on dashboard reporting. A unified system that integrates all these components into a single deployable platform remains largely unexplored.

This paper surveys six representative studies from 2024–2025 that address AI-driven logistics emission management. We critically analyze their methodologies, datasets, key contributions, and limitations, and then present the design of a proposed Carbon Footprint Tracking System for Logistics that aims to overcome identified gaps through a holistic, AI-powered web platform.

A. Research Contributions

This survey and the associated proposed system make the following research contributions:

- A structured comparative analysis of six recent AI-based logistics emission management studies.
- Identification of critical gaps in existing literature related to real-time tracking, multi-parameter prediction, and integrated dashboards.

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- Proposal of a unified web-based Carbon Footprint Tracking System incorporating ML-based emission prediction, eco-route optimization, shipment-level CO_2 tracking, and future emission forecasting.

II. RELEVANT LITERATURE

A. Paper 1: International Energy Agency (IEA) Transportation Emissions Report 2024

The IEA report [1] provides a comprehensive analysis of global transportation emissions trends through 2024. The report documents that road transport contributes over 75% of all transport-related CO_2 emissions, with freight vehicles representing a growing share. The IEA analysis employed aggregated statistical models and national inventory datasets to quantify emissions by vehicle category, fuel type, and geographic region.

The report identifies that without policy intervention, transport emissions could increase by 16% by 2030. Key parameters analyzed include vehicle kilometers traveled (VKT), average fuel economy, and carbon intensity of fuels. A significant limitation of the IEA approach is its reliance on top-down national-level data, which lacks the shipment-level granularity needed for logistics-specific carbon management. The report does not present a deployable tool for real-time monitoring or route-level emission calculation.

B. Paper 2: AI-Based Green Logistics Optimization (Zhang et al., 2024)

Zhang et al. [2] proposed a multi-objective optimization framework for green logistics using a hybrid approach combining genetic algorithms and deep reinforcement learning (DRL). Their system simultaneously minimized delivery time, fuel consumption, and CO_2 emissions across multi-depot vehicle routing scenarios. Experiments were conducted on synthetic datasets representing urban delivery networks with varying traffic densities.

The study demonstrated that DRL-based route optimization could achieve up to 18% reduction in total emissions compared to traditional shortest-path algorithms. However, the system was evaluated only on simulated environments without real-world logistics data integration. The authors did not address shipment-level carbon tracking or provide a user interface for logistics operators. Additionally, weather conditions and load weight variations were not incorporated into the emission model.

C. Paper 3: AI-Driven Scope 3 Carbon Emissions for Sustainable University Transportation (Manju Rani et al., 2025)

Manju Rani, Bhavesh Vyas, Vineet Dahiya, and Puja Acharya [3] developed an AI-driven model specifically targeting Scope 3 carbon emissions in university transportation systems. Their approach used a combination of Natural Language Processing (NLP) for extracting transport activity data from institutional reports and supervised ML classifiers for emission categorization. The model achieved 87% accuracy in classifying emission categories and demonstrated applicability to institutional sustainability reporting.

While innovative in its NLP-based data extraction approach, the system was constrained to institutional settings and Scope 3 boundary definitions. The model lacked route-level granularity and did not support real-time data ingestion from logistics sensors or GPS systems. Deployment as a general-purpose logistics emission tool was not addressed, and the system did not offer carbon reduction recommendations or forward-looking emission predictions.

D. Paper 4: Carbon Emission Prediction Using Machine Learning (Li & Qin, 2025)

Li and Qin [4] conducted a comparative study of machine learning algorithms for predicting carbon emissions in transportation systems. They evaluated Linear Regression, Random Forest, Gradient Boosting, and Long Short-Term Memory (LSTM) neural networks using a dataset of road freight trips with parameters including vehicle type, distance, speed, load factor, and fuel type. The LSTM model achieved the highest accuracy with a Mean Absolute Percentage Error (MAPE) of 4.3% on the test set.

This study represents one of the most rigorous ML benchmarking efforts for logistics emission prediction. However, it was limited to a prediction exercise without integration into an operational system. Traffic density and weather conditions were not included as model features despite their known impact on fuel consumption. The research did not address route optimization or provide a platform for continuous emission monitoring. A real-time deployment architecture was not proposed.

E. Paper 5: Carbon Footprint Monitoring in Smart Logistics Systems (Wang, 2025)

Wang [5] proposed a smart logistics carbon monitoring framework leveraging IoT sensor data and cloud computing. The system collected real-time telemetry data from delivery vehicles including GPS coordinates, engine RPM, fuel flow rate, and ambient temperature. This data was processed through a cloud analytics pipeline to compute per-trip emission estimates and aggregate carbon dashboards for fleet managers.

The system demonstrated strong real-time monitoring capabilities and was validated on a fleet of 50 commercial vehicles over three months. Key limitations included high hardware deployment costs due to IoT sensor requirements and dependency on uninterrupted network connectivity. The system did not incorporate AI-based route optimization or future

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emission forecasting. Machine learning-based anomaly detection for unusual emission events was identified as future work.

F. Paper 6: Comparison of Route Optimization Approaches for Emission Reduction

A supplementary study in the IEA comparative series examined multiple route optimization strategies including Dijkstra's algorithm, A* search, and heuristic bio-inspired methods for emission-aware routing in logistics networks [6]. The study evaluated these approaches on standard benchmark datasets (Solomon VRPTW instances) and real city network graphs. Results indicated that bio-inspired methods such as Ant Colony Optimization (ACO) produced routes with 12–15% lower estimated emissions than classical shortest-path algorithms.

While the route optimization analysis was rigorous, the study did not integrate emission prediction models into the routing decisions. Emission estimates were derived from fixed emission factors rather than ML predictions, limiting adaptability to real-world variability. No deployed system or user interface was presented, and the research did not address shipment-level tracking or historical emission analytics.

III. COMPARATIVE ANALYSIS OF EXISTING SYSTEMS

Table I presents a structured comparison of the six reviewed studies across critical dimensions relevant to logistics carbon management.

TABLE I. COMPARISON OF EXISTING RESEARCH ON CARBON EMISSION MANAGEMENT IN LOGISTICS

Ref.	Year	AI Model Used	Route Opt.	Real-Time Tracking	Key Limitation
[1] IEA	2024	Statistical Models	No	No	No shipment-level granularity
[2] Zhang et al.	2024	DRL + Genetic Algorithm	Yes	No	No real-world data, no UI
[3] Rani et al.	2025	NLP + SVM	No	No	Scope 3 only, institutional
[4] Li & Qin	2025	LSTM, Random Forest	No	No	Prediction only, no deployment
[5] Wang	2025	IoT + Cloud Analytics	No	Yes	High IoT cost, no ML prediction
[6] IEA Series	2025	ACO, A* Search	Yes	No	Fixed emission factors, no UI

IV. GAP ANALYSIS

Based on the review of the six studies, the following critical gaps are identified in the existing literature:

A. Absence of Unified Integrated Platforms

Existing research addresses individual components of the logistics carbon management problem in isolation. Route optimization studies do not include emission prediction models, while prediction studies do not offer routing or tracking capabilities. No single deployable system integrates all necessary components—prediction, routing, tracking, and analytics—into a unified web platform accessible to logistics operators.

B. Limited Multi-Parameter Emission Models

Most existing models use a restricted set of parameters for emission calculation, typically limited to distance and vehicle type. Critical variables such as traffic density, load weight, weather conditions, and route terrain type are rarely incorporated simultaneously. This reduces the accuracy and real-world applicability of emission estimates, particularly for dynamic logistics environments.

C. Lack of Real-Time and Shipment-Level Tracking

While Wang [5] demonstrated real-time IoT-based monitoring, this approach requires significant hardware investment and is not scalable for small and medium logistics operators. No software-only solution providing shipment-level carbon tracking with real-time emission updates has been presented in the reviewed literature.

D. No Future Emission Forecasting

None of the reviewed systems offer forward-looking emission predictions that would allow logistics companies to plan operations proactively to meet emission reduction targets. Predictive analytics for carbon management remains largely unexplored in the context of operational logistics planning.

E. Absence of Actionable Recommendations

Existing systems report emissions but do not generate specific, actionable recommendations for reducing carbon output. Carbon reduction guidance—such as vehicle type switching, load consolidation suggestions, or optimal departure time recommendations—is absent from all reviewed approaches.

V. PROPOSED SYSTEM DESIGN

A. System Overview

To address the identified gaps, we propose a web-based Carbon Footprint Tracking System for Logistics (CFTSL). The system follows a three-tier architecture comprising a Presentation Layer built with React.js, an Application Layer implemented using Flask RESTful API, and a Data & Intelligence Layer incorporating ML models and a relational database.

The core design principle is to provide a software-only, deployable solution accessible to logistics operators without specialized hardware requirements. The system accepts standard logistics operational data as input and delivers comprehensive emission insights, optimized routes, and carbon reduction guidance through a centralized dashboard.

B. System Workflow

The end-to-end workflow of the proposed CFTSL system follows a structured sequence:

- User inputs delivery details: source location, destination, vehicle type, load weight, and route preferences.
- The system fetches map and real-time traffic data via integration with Google Maps API or OpenRouteService.
- Multiple candidate routes are generated and analyzed for CO_2 emission using the ML prediction model.
- The AI-powered route optimization module selects and recommends the carbon-efficient route.
- Emission results are displayed on the dashboard with route map, CO_2 estimates, and fuel consumption data.
- Trip data is stored in the database, and carbon reduction recommendations are generated.
- Historical analytics enable longitudinal emission trend analysis and future emission forecasting.

C. AI Components

The Intelligence Layer integrates two primary AI components:

AI Component 1: ML-Based Emission Prediction Model - A Gradient Boosting Regressor trained on logistics trip data with features including vehicle type, fuel type, distance, load weight, traffic density, weather conditions, and route type. The model outputs estimated CO_2 emissions in kilograms per trip with a target MAPE below 5%.

AI Component 2: Eco-Route Optimizer - A route scoring algorithm that combines emission predictions with routing graph search to identify the lowest-emission feasible route among generated alternatives. The optimizer balances emission minimization with delivery time constraints, ensuring operational viability.

D. Key Parameters

The proposed system incorporates a comprehensive set of emission-relevant parameters:

- Vehicle Type: Diesel truck, petrol van, electric vehicle, motorcycle
- Fuel Consumption Rate: Liters per 100 km, estimated from vehicle specifications
- Travel Distance: Computed from map API route data
- Traffic Density: Real-time congestion index (low, medium, high)

- Load Weight: Cargo weight in kilograms
- Weather Conditions: Temperature, wind speed, precipitation
- Route Type: Highway, urban road, rural road

VI. EXPECTED OUTCOMES AND BENEFITS

A. Emission Accuracy

The multi-parameter ML model is expected to achieve emission prediction accuracy superior to fixed emission factor approaches, with an estimated MAPE below 5% on diverse logistics route datasets. Incorporating traffic and weather conditions as dynamic features is projected to reduce prediction error by 15–20% compared to distance-only models.

B. Route Emission Reduction

By identifying and recommending carbon-efficient routes over conventional shortest-path alternatives, the system is expected to deliver 10–18% reduction in per-trip CO_2 emissions for participating logistics operators, consistent with results reported by Zhang et al. [2] and the IEA Series study [6].

C. Operational Benefits

The centralized dashboard and shipment-wise carbon tracking provide logistics companies with actionable insights to identify high-emission routes and vehicles, optimize fleet deployment, and reduce unnecessary fuel consumption. Future emission forecasting enables proactive operational planning aligned with organizational sustainability targets.

D. Accessibility and Scalability

As a web-based software-only solution, the CFTSL system is deployable without specialized IoT hardware, making it accessible to small and medium logistics enterprises. The modular architecture supports horizontal scaling to accommodate multiple concurrent users and large logistics fleets.

VII. CONCLUSION AND FUTURE WORK

This paper presented a comprehensive survey of six recent studies on AI-based carbon emission management in logistics and transportation systems. The reviewed works collectively demonstrate the viability and necessity of AI-driven approaches to logistics carbon management but reveal significant gaps in integration, real-time capability, multi-parameter modeling, and actionable guidance.

To address these gaps, we proposed the Carbon Footprint Tracking System for Logistics (CFTSL)—a unified, web-based platform that integrates ML-based emission prediction, eco-route optimization, shipment-level CO_2 tracking, future emission forecasting, and carbon reduction recommendations. The system is designed to be accessible, scalable, and deployable without specialized hardware requirements.

Key achievements of this work include the identification of five critical gaps in existing literature, the proposal of a holistic AI-powered logistics emission management architecture, and the definition of a comprehensive multi-parameter emission model incorporating vehicle type, traffic density, load weight, weather, and route characteristics simultaneously. Future work will focus on implementation and validation of the proposed system on real logistics datasets, incorporation of federated learning for privacy-preserving model training across multiple logistics operators, and pursuit of integration with national carbon accounting frameworks to support regulatory reporting requirements.

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