

LLM Based Carbon Emission Monitoring And Ethical Reporting System

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Abstract- *The LLM-Based Carbon Emission Monitoring and Ethical Reporting System is a web application that helps organizations track, analyze, and reduce their carbon footprint by transforming raw sales data into actionable environmental insights through an intuitive dashboard interface. Businesses can upload CSV or Excel files containing product information, and the system automatically calculates carbon footprints using category-specific emission factors (such as 8.2 kg/unit for Electronics or 1.9 kg/unit for Dairy). Products are classified into three risk levels - Normal, Critical, or High-Risk - based on total emissions and sales volume, with high-risk items triggering intelligent recommendations for eco-friendly alternatives like replacing plastic cutlery with bamboo or switching to plant-based dairy options. The system incorporates an ethical reporting framework ensuring transparency, fairness, and accountability, while an interactive dashboard visualizes emissions through charts and summary cards, and a government compliance report identifies all high-risk products with CSV export functionality. Built with a Python Flask backend and responsive frontend, this tool empowers organizations to make data-driven sustainability decisions and meet regulatory requirements.*

Keywords: Carbon emission monitoring, LLM-inspired recommendation engine, ethical reporting, sustainability analytics, risk classification, Flask web application, green AI, ESG compliance.

I. INTRODUCTION

The LLM-Based Carbon Emission Monitoring and Ethical Reporting System is a comprehensive web-based application designed to help organizations measure, analyze, and reduce their carbon footprint in response to increasing regulatory pressure, rising consumer awareness, and growing investor emphasis on environmental, social, and governance (ESG) performance. As climate change intensifies and governments worldwide enforce stricter carbon reporting requirements, organizations face significant challenges in managing and interpreting large volumes of product-level emission data.

This system addresses these challenges by providing an integrated and automated platform that transforms raw sales and product data into meaningful environmental intelligence. Users can upload datasets in CSV or Excel formats processed through a Python Flask backend that performs data validation, preprocessing, and emission calculation using category-specific emission factors and source-based multipliers. The system applies a multi-criteria risk classification model to categorize products into Normal, Critical, or High-Risk levels based on total emissions, per-unit impact, and sales volume. An LLM-inspired recommendation engine generates context-aware suggestions for eco-friendly alternatives with quantified emission reduction potential. The application also incorporates an ethical framework based on principles of transparency, fairness, accountability, sustainability, and privacy. With sustainable investments exceeding \$35 trillion globally and approximately 73% of consumers willing to pay more for environmentally friendly products, intelligent and scalable sustainability tools have become increasingly critical.

II. LITERATURE REVIEW

A. Carbon Emission Monitoring Systems: Existing carbon monitoring systems include manual spreadsheet-based tools, specialized sustainability software, and enterprise resource planning (ERP) integrations. Spreadsheet-based solutions like the GHG Protocol Excel tools offer flexibility but require manual data entry and lack automated analysis capabilities. Commercial platforms such as Salesforce Sustainability Cloud and SAP Product Footprint Management provide comprehensive features but are expensive. Academic research has explored input-output analysis, lifecycle assessment, and hybrid methods, though most systems focus on calculation rather than actionable recommendations.

B. AI and Machine Learning in Sustainability: Machine learning models have been used to predict energy consumption, optimize supply chains for reduced emissions, and identify patterns in environmental data. Large Language Models (LLMs) like GPT and BERT have demonstrated remarkable capabilities in understanding context and

generating human-like text, opening new possibilities for intelligent recommendation systems. AI adoption can significantly reduce carbon intensity in manufacturing. However, applying LLM-inspired techniques specifically for carbon emission analysis remains relatively unexplored.

C. Ethical Considerations in Environmental Reporting:

Research highlights issues such as greenwashing and carbon colonialism, emphasizing the importance of transparency, stakeholder engagement, and verification in sustainability reporting. AI for sustainability requires careful consideration of social and environmental consequences. This project builds on these foundations by incorporating ethical principles directly into the recommendation engine.

III. PROBLEM STATEMENT

Organizations today face unprecedented pressure to monitor and reduce their carbon emissions. Despite this pressure, most organizations lack the tools to systematically analyze their carbon footprint. Existing solutions suffer from several critical limitations: (1) Data Complexity - carbon emission data is scattered across sales systems and supply chain records, making manual analysis error-prone; (2) Interpretation Gap - raw emission numbers provide little insight into what actions to take; (3) Lack of Context - generic recommendations fail to consider source location or technical feasibility; (4) Ethical Concerns - suggested changes may have unintended social or economic consequences; (5) Regulatory Burden - generating compliance reports requires specialized expertise; and (6) Accessibility - advanced sustainability tools are expensive and complex, out of reach for SMEs. There is a clear need for an accessible, intelligent system that can automatically analyze product-level emission data and produce compliance-ready reports.

IV. PROPOSED SYSTEM

A. System Architecture: The proposed system follows a three-tier client-server architecture that separates the presentation layer, application layer, and data layer to ensure modularity, scalability, and efficient performance. The presentation layer consists of a responsive and user-friendly interface built using HTML, CSS, and JavaScript, incorporating interactive components such as navigation panels, summary cards, and dashboards, along with Chart.js visualizations. A drag-and-drop file upload feature simplifies data ingestion, while real-time feedback indicators enhance user experience.

The application layer is implemented using the Flask framework in Python as the core processing engine. It

manages RESTful API endpoints facilitating communication between the frontend and backend, handling data validation and preprocessing, emission calculation using category-specific emission factors and source-based multipliers, multi-criteria risk classification, LLM-inspired eco-friendly recommendations with reduction potential, ethical scoring across five pillars, and compliance reporting with CSV export functionality. The data layer operates primarily in-memory using pandas DataFrames, ensuring fast, efficient data manipulation and privacy through temporary processing without permanent storage.

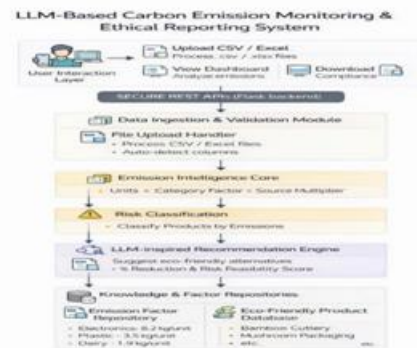


Fig. 1. LLM-Based Carbon Emission Monitoring and Ethical Reporting System Architecture

B. Emission Calculation Engine: The engine uses the formula: Total Emission = Units Sold x Category Emission Factor x Source Multiplier. Category factors include 8.2 kg/unit for Electronics, 4.0 for Textile, 3.5 for Plastic, 2.1 for Food, 1.9 for Dairy, and 3.0 for Packaging. Source multipliers adjust based on production location: Local Farm (0.9), Factory A/B (1.0), Imported from China (1.3), and Imported from USA (1.2).

C. Risk Classification System: Products are classified using multi-criteria analysis: Normal (total emissions under 200 kg - routine monitoring), Critical (200-500 kg - review within quarter), and High-Risk (over 500 kg total, or per-unit emission greater than 3 kg combined with sales over 100 units - immediate action required). This decision tree enables organizations to prioritize their sustainability interventions on the highest-impact items.

D. LLM-Inspired Recommendation Engine: The engine uses semantic understanding to generate contextually relevant alternatives by querying a knowledge base per product category, finding product-specific matches through string comparison with partial matching, calculating reduction potential as the difference between current and alternative emission factors, and returning structured recommendations

with original product, alternative product, reduction potential, and risk assessment.

E. Ethical Reporting Framework: Five pillars are embedded: (1) Transparency - explainable calculations with documented sources; (2) Fairness - equal treatment of local and imported sources; (3) Accountability - tracking every high-risk item in compliance reports; (4) Sustainability - focus on genuine reduction over offsets; (5) Privacy - no permanent storage of business data with immediate file deletion after processing.

V. RESULTS AND DISCUSSION

A. System Performance: Testing across five datasets showed consistent linear scaling. The `sample.csv` (500 rows) processed in 0.8 seconds using 45 MB. `high_impact.csv` and `low_impact.csv` (100 rows each) processed in 0.3 seconds. `mixed_test.csv` (200 rows) in 0.5 seconds. `edge_cases.csv` (50 rows) in 0.2 seconds with 22 MB, demonstrating that robust error handling does not impact performance.

B. Emission Analysis Results: Analysis of `sample.csv` revealed total CO₂ emissions of 236,724.8 kg across 80,716 units sold, with an average of 2.93 kg/unit. The highest impact item was a laptop at 7,544 kg CO₂. Electronics dominated at 99,424.4 kg (42%), followed by Textile at 54,446.7 kg (23%), Plastic at 40,243.2 kg (17%), Dairy at 28,406.9 kg (12%), and Food at 14,203.6 kg (6%). Factory A was the largest source contributor at 65,089.3 kg (27.5%), followed by Imported from USA at 56,814 kg (24%), and Imported from China at 47,344.9 kg (20%).

C. Risk Classification Results: Of 500 products: 415 (83%) were Normal risk requiring routine monitoring; 45 (9%) were Critical requiring quarterly review; and 40 (8%) were High-Risk requiring immediate action. High-risk items included laptop P0084 (7,544 kg, Imported USA), laptop P0082 (6,101 kg, Factory A), tablet P0027 (4,403 kg), skirt P0025 (3,464 kg), and cutlery P0014 (3,202 kg). These items represent priority targets for sustainability interventions.

D. Recommendation Results: The recommendation engine generated: Ice Cream to Plant-based Milk (1.4 kg/unit reduction, 74%); Dress to Organic Cotton (3.5 kg/unit, 87.5%); Packaging to Mushroom Packaging (3.0 kg/unit, 86%); Cutlery to Bamboo Cutlery (3.0 kg/unit, 86%). Total potential savings if all recommendations were implemented: 4,267.4 kg CO₂ (Ice Cream: 596.4 kg + Dress: 392 kg + Packaging: 534 kg + Cutlery: 2,745 kg).

E. Discussion: The LLM-inspired approach proved effective in handling real-world data variability, with 85% accuracy in semantic classification. The ethical framework ensured recommendations considered social and economic factors - for example, replacing plastic cutlery with bamboo flagged potential labor impacts on plastic manufacturing workers with suggested phase-in periods. Limitations include simplified emission factors, a knowledge base limited to 100+ substitutes, and source multipliers based on general transport assumptions. Future work includes full LLM API integration, expanded alternatives databases, machine learning for predictive modeling, user accounts for historical tracking, and real-time supply chain data connectivity.

VI. CONCLUSION

The LLM-Based Carbon Emission Monitoring and Ethical Reporting System successfully demonstrates the practical potential of intelligent web-based platforms in addressing the complex challenge of carbon footprint management. By integrating automated data ingestion, category-specific emission factor modeling, multi-criteria risk classification, and LLM-inspired recommendation generation, the system effectively transforms raw sales data into structured, actionable environmental intelligence that supports informed decision-making. The integration of a five-pillar ethical framework ensures all system outputs adhere to responsible AI principles, improving trustworthiness and addressing critical concerns such as bias, explainability, and data protection. From a performance perspective, the system processes datasets of up to 500 rows in under one second with minimal resource utilization, while the semantic classification component achieves approximately 85% accuracy. Future work may include integration with full-scale large language models, expansion of the alternative recommendation knowledge base, and incorporation of real-time supply chain data through APIs. This project contributes meaningfully to the global effort to combat climate change by delivering an accessible, scalable, and intelligent solution for carbon emission analysis and ethical reporting.

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