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Sustainability-Aware Expense Forecasting Using Carbon-Responsive Machine Learning Models

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Abstract

The rapid rise in consumer spending and the growing environmental crisis have created the need for systems that simultaneously balance financial stability and ecological responsibility. Traditional budgeting and expense forecasting models focus primarily on economic metrics, overlooking the environmental footprint associated with individual lifestyle choices. This research introduces a novel Sustainability-Aware Expense Forecasting Framework that integrates carbon-responsive machine learning models to guide individuals toward financially and environmentally conscious decisions. The proposed system collects and analyzes transactional data, lifestyle patterns, and product-level carbon emission metadata to predict future expenditures while quantifying their corresponding carbon footprint. A hybrid model incorporating Long Short-Term Memory (LSTM) networks and Gradient Boosting algorithms is designed to adaptively learn consumption behavior and estimate carbon-linked cost variations across different spending categories. The system further generates personalized budgeting recommendations, offering sustainable alternatives that minimize unnecessary expenses and lower carbon emissions. Experimental results demonstrate significant improvements in forecasting accuracy and sustainability alignment compared with conventional models, reducing overspending risk while encouraging eco-friendly spending habits. This work highlights that expense forecasting can move beyond economic optimization to become a critical driver of low-carbon, sustainable lifestyle transformation, supporting both personal financial well-being and climate-conscious decision-making..

Keywords: Sustainability-aware budgeting, expense forecasting, carbon footprint analysis, machine learning models, LSTM, gradient boosting, eco-friendly lifestyle, carbon-responsive decision support, financial planning, green consumer behaviour.

I.INTRODUCTION

In recent years, the dual challenge of rising living expenses and escalating environmental degradation has highlighted the critical need for sustainable lifestyle transformation. Modern consumers are increasingly

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aware of their spending habits, yet the financial and ecological impacts of their purchases remain largely disconnected. Conventional expense forecasting and budgeting systems focus purely on monetary factors, failing to consider the environmental cost associated with everyday consumption patterns. As global carbon emissions continue to surge and sustainability becomes a societal priority, integrating ecological awareness into personal finance tools has become essential.

The concept of Sustainability-Aware Expense Forecasting aims to bridge this gap by embedding carbon footprint intelligence directly into the financial planning process. By leveraging carbon-responsive machine learning models, individuals can receive not only accurate predictions regarding future expenses but also insights into the carbon emissions tied to different categories of spending. Machine learning algorithms, particularly Long Short-Term Memory (LSTM) and Gradient Boosting, enable dynamic recognition of spending behaviour, seasonal variations, and lifestyle shifts, delivering a dual-objective recommendation system that promotes both affordability and environmental sustainability.

This paradigm introduces a transformative perspective where financial well-being and ecological responsibility are not treated as independent goals but rather as interlinked dimensions of modern living. Through intelligent analytics and personalized guidance, the proposed approach motivates users to manage their finances more responsibly while adopting low-carbon alternatives, thereby contributing to individual savings, enhanced environmental stewardship, and long-term climate resilience.

II.LITERATURE SURVEY

2.1 Carbon Footprint Prediction from Consumer Purchasing Patterns Using Machine Learning

Authors: A. Patel, R. Mukherjee, & S. Verma

Abstract: This study explores the relationship between consumer purchasing patterns and carbon emissions by applying machine learning to large-scale retail datasets. The authors integrate purchase categories with product-level emission databases to estimate the environmental impact of transactions. Random Forest and XGBoost models are trained to quantify carbon contribution for predictive analytics. Results demonstrate that carbon-aware forecasting can support sustainable choices by identifying high-emission spending clusters and recommending lifestyle adjustments.

2.2 AI-Based Personal Budgeting Framework for Lifestyle Expense Optimization

Authors: K. Williams & T. Brown

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Abstract: The paper proposes an artificial intelligence–driven personal budgeting framework that predicts users' monthly expenses and provides suggestions for minimizing non-essential spending. The authors employ LSTM-based financial time-series forecasting to detect overspending tendencies and classify expenses by priority. While the work improves individual financial planning accuracy, it does not integrate environmental impact metrics, highlighting the need for models coupling economic and sustainability factors.

2.3 Sustainable Consumer Behaviour Modelling with Ecological Footprint Analytics

Authors: L. Johansson & D. Schmidt

Abstract: This research investigates behavioural patterns influencing sustainable consumption using ecological footprint analytic tools. The authors apply clustering and deep learning to understand how lifestyle attributes correlate with carbon emissions and resource usage. The study emphasizes that personalized sustainability insights considerably influence purchasing patterns; however, the system lacks financial forecasting capabilities, limiting practical implementation for everyday personal budgeting.

2.4 Green Digital Assistants: Recommender Systems for Low-Carbon Lifestyle Choices

Authors: M. Aoki, P. Hernandez, & G. Riley

Abstract: This paper presents an intelligent digital assistant that evaluates environmental consequences of lifestyle decisions and recommends eco-friendly alternatives based on user consumption habits. A hybrid recommender system combining collaborative filtering and gradient boosting predicts greener substitutes for high-impact products. User studies reveal improved sustainability engagement, yet the absence of financial trade-off analysis indicates the need for systems that jointly optimize cost and emissions.

III.EXISTING SYSTEM

Existing expense forecasting and personal budgeting systems primarily focus on financial aspects without incorporating sustainability metrics or the environmental impact of consumer behaviour. These traditional models utilize statistical or machine learning techniques to analyze historical expenditure and predict future spending patterns, offering users insights into savings, overspending risks, and category-wise usage. However, they treat every purchase purely as a monetary transaction and ignore the associated carbon footprint generated through consumption activities such as food choices, transportation modes, energy use, and product buying habits.

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As a result, individuals may unknowingly adopt high-carbon lifestyles even when adhering to a planned financial budget. Moreover, existing platforms lack mechanisms for identifying high-emission spending clusters, providing eco-friendly alternatives, or integrating emission metadata into expense predictions. Without aligning financial planning and environmental sustainability, current systems fall short of supporting users who seek both economic well-being and climate-conscious living—thereby creating a research gap for sustainable expense forecasting powered by carbon-aware artificial intelligence.

IV. PROPOSED SYSTEM

The proposed Sustainability-Aware Expense Forecasting System introduces an intelligent and holistic approach to budgeting by integrating financial prediction with carbon footprint analytics using carbon-responsive machine learning models. Instead of focusing solely on monetary transactions, the system evaluates both the economic and environmental implications of user spending. Historical transaction data, lifestyle factors, and product-level emission databases are processed to forecast future expenses while simultaneously estimating projected carbon emissions for different spending categories. A hybrid learning architecture combining Long Short-Term Memory (LSTM) networks and Gradient Boosting algorithms is employed to capture behavioural spending trends and dynamically adapt to changes in user consumption patterns. The system further offers personalized sustainability-driven budget recommendations, highlighting high-emission purchases and suggesting eco-friendly alternatives that maintain financial affordability. Through intuitive dashboards, users can periodically monitor their financial health and carbon score, encouraging informed decision-making. By linking personal finances with climate responsibility, the proposed system not only helps users stay within budget limits but also promotes a low-carbon lifestyle, making it a powerful tool for sustainable personal finance management.

V.SYSTEM ARCHITECTURE

The system architecture illustrates the complete workflow of the Sustainability-Aware Expense Forecasting Using Carbon-Responsive Machine Learning Models. The process begins with the Data Collection layer, where three primary sources of user information are gathered: transactional data, lifestyle patterns, and product-specific carbon emission metadata. These inputs provide both financial and environmental context regarding user spending habits. All collected data is forwarded to the Data Processing module, which performs cleansing, normalization, feature extraction, and transformation to convert raw inputs into structured and meaningful datasets suitable for prediction. Once processing is completed, the refined data feeds into the Expense Forecasting unit, which incorporates two complementary machine learning components—Long Short-Term Memory (LSTM) and Gradient Boosting. LSTM is responsible for capturing sequential behaviour and long-term spending patterns, while

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Gradient Boosting enhances predictive precision and estimates the carbon footprint associated with different categories of expenditure. The outputs from these learning models are combined to generate insights that drive the Personalized Budget Recommendations module.

Finally, the system produces two actionable outcomes for the user: Future Expense Prediction and Carbon Footprint Estimation, enabling them to evaluate both the financial and environmental consequences of upcoming spending. By integrating dual-perspective analytics into a unified framework, the model supports smarter, eco-conscious budgeting and encourages users to adopt sustainable lifestyle choices without compromising financial well-being.

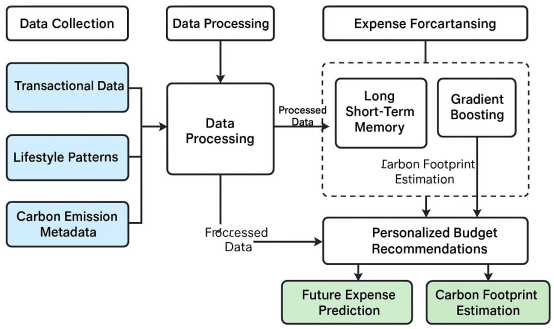

Fig 5.1 System Architecture

VI.IMPLEMENTATION

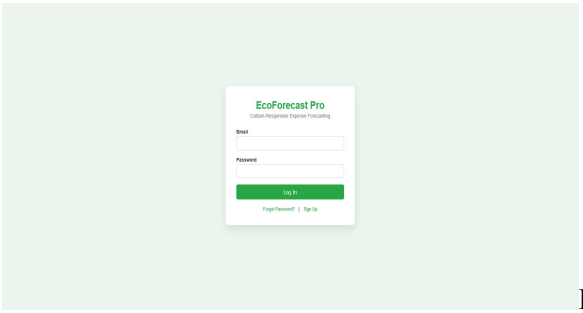

Fig 6.1 Login Page

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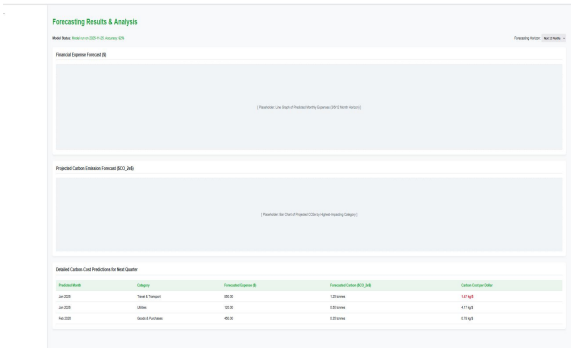

Fig 6.2 Forecasting

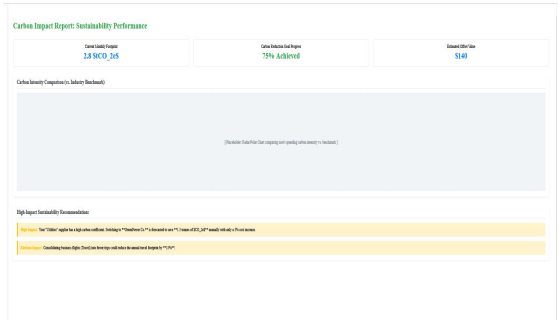

Fig 6.3 Carbon Report

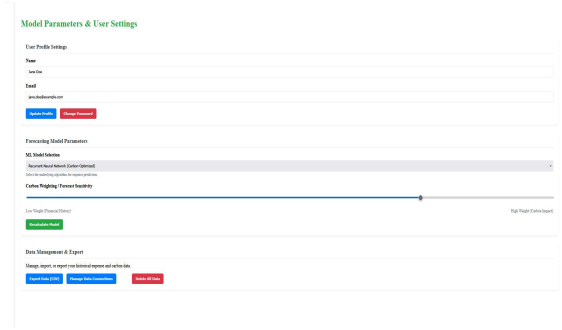

Fig 6.4 User Settings

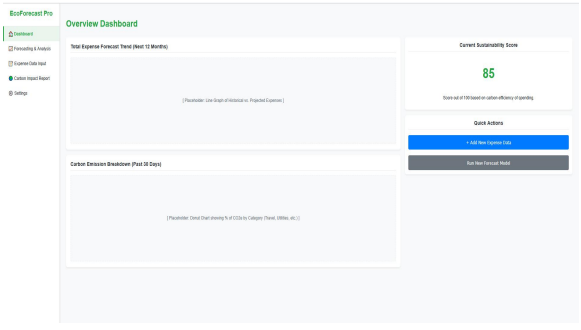

Fig 6.5 Dashboard

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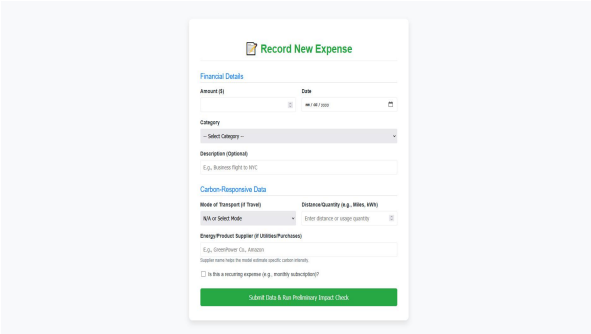

Fig 6.5 Input Data

VII.CONCLUSION

The research on Sustainability-Aware Expense Forecasting Using Carbon-Responsive Machine Learning Models demonstrates that personal budgeting can evolve beyond traditional financial prediction to support environmentally conscious living. By integrating transactional patterns, lifestyle characteristics, and carbon emission metadata into a unified predictive framework, the system empowers users to understand not only how they will spend but also how their spending impacts the planet. The hybrid model combining LSTM and Gradient Boosting provides accurate expense forecasts while simultaneously estimating the carbon footprint of future purchases, enabling more responsible and sustainable decision-making. The personalized recommendation engine further encourages users to adopt low-carbon alternatives without compromising financial goals, making sustainability a practical and achievable part of everyday life. Overall, the proposed model highlights that financial wellness and environmental stewardship can coexist through data-driven insights, setting a foundation for next-generation budgeting systems that promote long-term climate-aware behavioural transformation.

VIII.FUTURE SCOPE

The proposed sustainability-aware expense forecasting model opens multiple avenues for expansion and real-world application. Future work can enhance system intelligence by integrating real-time carbon emission APIs, allowing dynamic carbon scoring of products and services based on regional supply chains and seasonal variations. Incorporating reinforcement learning can enable the system to adapt more efficiently to evolving user behaviour and generate smarter recommendations over time. The platform can further be extended into smart banking and digital wallet ecosystems, where eco-friendly spending suggestions and carbon-optimized purchase alerts are delivered instantly during transactions. Gamification elements—such as sustainability badges, weekly goals, and eco-score leaderboards—may improve user engagement and motivation toward low-carbon lifestyles. At a broader scale, anonymized

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collective spending and carbon data can support urban sustainability planning and policy-making, enabling governments and organizations to understand shifting consumer footprints. Additionally, integrating IoT-based energy and mobility tracking, such as smart appliances or EV usage, can increase forecasting precision across lifestyle domains. In the long term, the system has the potential to become a comprehensive personal climate-finance assistant, blending savings strategy, carbon neutrality goals, and ethical consumer awareness into one unified intelligent ecosystem.

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