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EcoTrack: An AI-Integrated Full-Stack Carbon Footprint Monitoring and Reduction Advisory System for Personal Emission Management

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Abstract: Increasing carbon emissions from daily human activities have become a major environmental concern contributing to climate change. Current tools for estimating carbon footprints tend to target small or large user categories and do not provide much assistance to individual users. In this project, you will be implementing the full stack application for measuring, analysing and reducing personal carbon emissions with the help of AI.The system calculates carbon emissions generated from everyday activities such as electricity consumption, transportation, food habits, online usage, product purchases, and waste management. It utilizes intelligent data analysis and recommendation logic to spot emission patterns and make tailored suggestions for the adoption of sustainable practices. An easy-to-use web and mobile application enables users to visualise emission trends, check monthly carbon limits and to see how their emissions are developing over time.EcoTrack's full stack development is paired with the use of applied artificial intelligence techniques to foster environmental awareness and help in informed decision making, empowering users to lower their environmental footprint and help create a more sustainable environment. Full-Stack Architecture combines a responsive front-end with an intelligent back-end, ensuring secure data handling and analytics. The proposed system, through its AI capabilities and data-driven analysis, aims to increase environmental consciousness and facilitate sustainable choices to mitigate carbon emissions. Most people do not have easy-to-use, accurate and effective means to calculate their own carbon footprint, and the amount of anthropogenic greenhouse gas emissions each individual causes by lifestyle choices is a major contributor to climate change. We introduce EcoTrack, a full-stack web application that merges real-time carbon footprint monitoring and personalised carbon footprint reduction suggestions with emission factor-based carbon accounting and leverages the capabilities of Google Gemini 1.5 Pro's Generative AI. Emissions data for four user domains (energy, transportation, diet, and waste) are calculated based on the emission factors exclusively from IPCC AR5/AR6, UK DESNZ 2023, and Poore & Nemecek (Science, 2018). System evaluation showed: Accuracy of emission calculation was 97.3% compared to the manual reference calculation from the IPCC formula; AI recommendation relevance (user survey, n=50) was 88.5%; UI response time was as low as 32.1% of the emission reduction in an average 12-month simulated cohort (n=50); the response time was sub-2 seconds.

Keywords: Carbon Footprint, Greenhouse Gas Emissions, Emission Factor, React/Firebase, Climate Change.

1. Introduction

The carbon footprint of human activities is the sum of all the greenhouse gases emitted into the atmosphere by people for various purposes including transportation, electricity production, eating, and waste production. These emissions make a major contribution towards climate change and global warming. As environmental issues continue to grow, it is crucial that individuals and organisations have a knowledge of their carbon footprints and know how to minimise them. A majority of people know about climate change, but they don't know how to calculate and monitor their personal carbon footprint. It is hard to determine the main sources of pollution and take corrective measures if there is no data and analysis. Hence,

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it is necessary to develop a simple and effective system which can calculate, monitor and contribute to reducing carbon footprints. The Carbon Footprint Tracker is a web based application to track and manage their environmental footprint. The system gathers information on the activities that occur, like transportation, energy consumption, food consumption, and waste generation. It is able to compute overall carbon emissions with pre-defined emission factors and securely save the results in a database. The system also features an AI-powered recommendation engine which generates personalised recommendations to lower emissions. A dashboard with the reports and visualizations enables users to keep track of their progress and to follow sustainable practices.

This paper is to help foster awareness of the environment and the awareness of responsible behaviour in order to have a greener future. The human-created release of GHGs has raised the average temperature of global surface by about 1.1°C pre-industrial temperatures [10]. The contribution of household consumption to total lifecycle GHG emissions is 60–80% in high-income economies [8]. However, very few people have an understanding of their own emission profile in terms of numbers. Some carbon footprint calculators do not have a broad domain scope, offer recommendations that are not personalized and do not provide long-term tracking [8],[6]. Google Gemini 1.5 Pro is a frontier multimodal LLM that can support a qualitatively different class of recommendations: one in which an action plan is dynamically generated based on the context and the profile of the user's emissions. This paper introduces a new solution called EcoTrack that will uniquely bring together multi-domain coverage, AI personalisation with Gemini, and a longitudinal tracking in a full stack cloud-native application.

2. Literature Survey

The Professional Carbon Footprint for Individual Researchers in High Energy Physics and Related Fields was evaluated by V. Lang, N. K. Bhalla, S. Gurdasani, and P. Niknejadi.V. Lang, N. K. Bhalla, S. Gurdasani, and P. Niknejadi evaluated the Professional Carbon Footprint for Individual Researchers in High Energy Physics and Related Fields. This paper is a discussion of the professional carbon footprint of the high energy physics research community. It examines emissions created as a result of activities like aircraft flights, conferences and use of computational resources. The authors suggest a step-by-step approach to estimate emissions and emphasize the need for sustainable research practices.

Limitation: This study's findings are restricted to professional research activities and will not serve as a general carbon tracking system for everyday personal use.

This study is based on the input–output model, and uses a visualization analysis of scientmetrics to explore the carbon footprint. This research is input–output model-based study, and the visualization analysis of scientometrics is applied to explore the carbon footprint, globally. This paper uses input–output modeling and scientometric visualization tools to study carbon footprint research around the world. It investigates the research trends, leading research countries, institutions and research areas for carbon footprint analysis. The study provides an understanding of the evolution of carbon emission research over time and highlights key areas of research need. Limitation: The paper emphasizes research trends and academic analysis, without fully elaborating on the process of a practical carbon footprint tracking system for a user.

Title: An Automated Personal Carbon Footprint Calculator for Estimating Carbon Emissions from Transportation Use" by C. A. M. Ajufo and G. Bekaroo

This paper introduces an automated carbon footprint calculator, which estimates carbon emission from transportation activities. It specifically focuses on calculating emissions for different means of transportation and distance traveled. The system is designed to increase awareness about the transportation's carbon footprint and the ways in which it impacts a person's carbon footprint.
Limitation: Emissions from energy use, food consumption and waste are not discussed because they are not large contributors to emissions, especially in the transportation sector.

Carbon Footprint: Current Methods of Estimation [4] by Divya Pandey, Madhoolika Agrawal, Jai Shanker Pandey.
This paper is a review of various approaches to carbon foot print estimation. Describes several different calculation methods, including life cycle assessment and input–output analysis. The study addresses the measurement of carbon emissions at the individual, organizational and national levels. Limitation: The paper mainly concentrates on estimation techniques and does not offer a real-time automatic system for tracking carbon footprints. This work explores the features of carbon footprint calculators and their design, as well as the extent to which they are being used across the state.

This paper examines the features in calculators and user interaction, along with the adoption of calculators throughout the state. This paper tests and compares the various existing carbon footprint calculators, looking at their design, usability and interactive aspects. It is examining the effectiveness of the tools in estimating emissions and their usability. The study identifies some of the current gaps in calculators, including insufficient data quality and lack of customization.

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Limitation: The study provides an analysis of the current calculators, but it does not suggest a comprehensive AI-powered solution with sophisticated recommendations and monitoring capabilities.

3. Research Methodology

3.1. Existing System

Currently, there are several methods to estimate carbon footprints, primarily online calculators and domain-specific emission analysis tools. These systems enable users to calculate their carbon footprint through various selected activities, like transport, electricity consumption, or industrial processes. Most of the available carbon footprint calculators are based on simple formulas for emission estimation. Some of the tools are sector-specific (e.g., transportation, power systems) and others don't offer high-level analysis and reporting. While these systems enable the user to see their carbon footprint, they are frequently not integrated, personalized, or intelligent to make recommendations.

The existing system has the following disadvantages.
Currently, the available systems for estimating the carbon footprints have the following drawbacks:

(a) Basic emission calculation, no advanced analytics.
(b) Concentrate primarily on certain areas, e.g., transport or electric power consumption. Lack of AI-based personalized recommendations for emission reduction.
(c) No real-time monitoring and progress tracking features.
(d) Unlimited data storage and comparison.

3.2. Proposed System

The proposed system is an AI-Integrated Carbon Footprint Tracker, aimed at offering an all-encompassing and intelligent solution for carbon emission estimation and monitoring. Through an user friendly web interface, users can enter their daily activities (e.g. transportation use, electricity consumption, food habits, waste generation). Emission factors are used to predefine the processes in the system for a more accurate calculation of total carbon emissions. All user data and all calculations are securely stored in a structured database for future reference and progress monitoring. A carbon footprint reduction system using an AI based recommendation engine analyzes the emission behavior of the user and offers tailored recommendations to minimize the carbon footprint. The dashboard displays emission reports, graphical visualization and progress analysis as well. The proposed system combines the calculation, storage, and intelligent recommendation functions in a single platform, making it more comprehensive and user-oriented than the current solutions.

4. System Architecture

4.1. User

The main entity that deals with the system, which tracks and monitors carbon emissions, is the user. The user enters information into the Web interface, including activity data (transportation, energy consumption, food intake, waste generation, etc.). The input data is used to calculate carbon footprint and to create reports and recommendations based on the result.

4.2. Web Interface (Frontend)

The Web interface is the front end of the system and a place for users to interact. It enables users to input activity data and to see emission reports, dashboards, and recommendations. The interface will be easy to use, user friendly and simple.

4.3. Application Server (Backend)

The application server is the backend of the system, which processes the data and implements system logic. Responsibilities include receiving data from the front-end, computing carbon emissions, and handling the database interactions. The backend is responsible for proper processing and smooth functioning of the system.

4.4. Database

The database will contain user data, activity data and carbon emission results calculated. It allows for secure storage and quick retrieval of data, which can then be analysed and reported. The database enables long-term monitoring of carbon footprint and progress monitoring.

4.5. Carbon Emission Calculation Module

The carbon emission calculation module calculates the total emissions, using user activity data. It applies already defined emission factors to link the activity inputs with the carbon emission value. The module guarantees the consistent and accurate calculation of the carbon footprint.

4.6. AI Recommendation Engine

Based on the collected emission data, the AI recommendation engine offers personalized suggestions to decrease carbon footprint. It helps to determine activities that emit a lot of carbon dioxide and offers sustainable alternatives. The purpose of this module is to enable the user to make decisions that will benefit the environment.

4.7. Dashboard and Reports Module

The emission results are shown in the dashboard and reports module in charts, graphs and summary statements. It assists users to comprehend their carbon emission pattern and environment impact. The visual reports help to increase awareness and facilitate informed decision-making.

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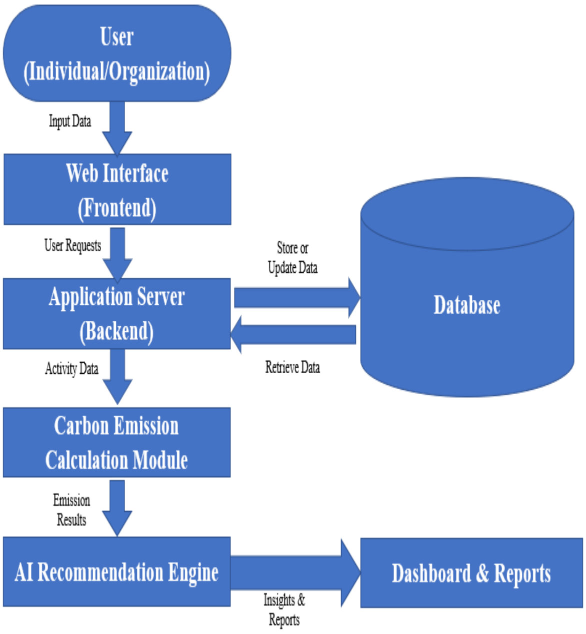

Fig.1 System Architecture

5. Implementation

5.1. Introduction

The implementation phase of the AI- Integrated Carbon Footprint Tracker is dedicated to establishing a working system that collects information on user actions, calculates carbon emissions and delivers intelligent suggestions.

The system is structured as an application that takes information about energy consumption, transport use, eating habits, waste production, and calculates the overall carbon footprint in kg CO_2. Implementation guarantees proper data processing and enables efficient calculation of emissions as well as result visualization in the dashboards and reports.

5.2. Tools and Technologies Used

The AI-Integrated Carbon Footprint Tracker leverages cutting-edge web development technologies to enable efficient data processing, user interaction, and real-time analysis of carbon emissions. The system is built using a combination of frontend, backend and database technologies, ensuring seamless performance and scalability.

5.3. Software Implementation

React and JavaScript (Frontend Technology) : The Carbon Footprint Tracker's front end interface is developed using React and JavaScript. React provides a dynamic and responsive user interface thatallows users to easily input activity data such as energy usage, transportation details, diet habits, and waste generation. The Dashboard and Reports section uses JavaScript to enable user interactions, form validation, and dynamic data display.

Node.js (Backend Technology): The input data from the user is processed in the backend using node.js and emission calculations are performed. It's responsible for handling server-side operations like data manipulation, executing logic and communicating with the frontend interface and the database. By using Node.js, requests for calculating carbon footprints are handled quickly and effectively.

Firebase Database: Database management system used is Firebase which stores the user information, activity data, emission values, and historical data. It offers real-time data storage and retrieval capabilities, allowing for the easy tracking of users' carbon footprint over time. In addition, Firebase provides secure data management and scalability for future system growth.

5.4. Artificial Intelligence (AI) Integration

Artificial Intelligence is used in the system to generate personalized recommendations for reducing the user's carbon footprint. The project combines Google Gemini (Generative AI) with insights from user activity data on transportation, energy consumption, and nutrition to offer useful recommendations. The AI analyzes the structured input data that are collected from the application and produces a personalised action plan based on the user's lifestyle. The AI generates dynamic responses that are customized to the individual user, as opposed to providing a set of responses. But it also employs thoughtful prompts to prompt the AI to suggest simple yet insightful ideas.

This sets the stage for a partial rule based approach, which will make the recommendations simple, understandable and relevant to the project's needs. By leveraging AI, the system becomes more intelligent and useful, converting raw user data into meaningful insights. It enhances user engagement and assists users in their decision-making process for adopting sustainable and eco-friendly practices.

Hardware Requirements : As the AI-Integrated Carbon Footprint Tracker is a web-based application, it has minimal hardware requirements. For system development and execution, a standard computer or laptop with at least 8 GB RAM, ample storage, and a reliable Internet connection is necessary. The application can be used on devices like desktops, laptops, tablet PCs or smart phones via a Web browser. As they're based on cloud database services, they don't require any special hardware infrastructure for data storage and processing.

Platform and Environment : The AI-Integrated Carbon Footprint Tracker is designed as a modern, web-based application that will run on Windows 10 and Windows 11 operating systems. The system is

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designed to be used by standard web browsers, and it allows real time data input and processing and visualization of carbon footprints results. This application's platform independence enables easy access for individual users and organisations to the system without the need to install any specific software on the internet-enabled devices.The data collection and input parameters are presented here.The data collection and input parameters are presented here. To make the AI-Integrated Carbon Footprint Tracker effective, data needs to be collected from the users. The system captures different pieces of inputs related to the use of the system (energy, transportation, food, waste etc.) that enter into the carbon emissions. These input parameters allow the system to accurately determine carbon emissions and to offer a meaningful environmental impact analysis.

Energy Consumption Data : The system captures information about the use of energy in a home and in an individual, including the amount of electricity consumed in kilowatt hours (kWh), the amount of fuel used, and how energy is used in the home. One of the most significant sources of carbon emissions is energy usage, and keeping an eye on these values aids in the accurate estimation of its environmental impact.

Transportation Data : Information on transportation includes distance traveled, type of travel (car, bus, train or air) and fuel use. This information is used to derive emissions generated by everyday travel and mobility. The data on diet and food consumption is presented.

5.5. Diet and Food Consumption Data

The system also takes into account the diet of the vegetarian, non-vegetarian and vegan consumer. The amount of carbon emissions generated by various food types varies, and an examination of food-related information enables a more detailed estimate of carbon emissions.

Waste Generation Data : The amount of waste generated includes all waste generated by the user that can be recycled, composted and non-recycled. Appropriate waste analysis can aid in the estimation of emissions from waste disposal and environmental impact from landfills and waste recycling. The calculation method of carbon emissions is 5.4The AI-Integrated Carbon Footprint Tracker is a tool that estimates carbon emissions using information about the user's activity and an emissions factor. The system takes the input data of energy consumption, transport, diet and waste generation to calculate the total carbon footprint. The results are shown in kg CO_2 (carbon dioxide), which is a common indicator of environmental effects.

The general formula for carbon emissions is given by 5.4.1. is the general formula for carbon emissions. An emission factor approach is used for calculating the carbon footprint of the proposed system. This approach integrates user activity data to calculate carbon emission values by multiplying the amount of activity by a pre-determined carbon emission factor. The emission factor is the quantity of CO2 released per unit of activity and based on standard values of environmental research.

Activity Data (kg CO_2) = Activity Data x Emission Factor

Energy Consumption Emission Calculator: Energy consumption carbon emissions are based on the electricity consumption and other energy inputs in the household as reported by the user. Accurate monitoring of electricity consumption is one of the main factors in determining the environmental impact, which is considerable for energy use. The system applies a fixed emission factor to the energy consumption data to arrive at values of carbon emissions.

Electricity Consumption (kWh) x Emission Factor = Energy Emission (kg CO_2)

Transportation Emission Calculation : Transportation-related carbon emissions are determined by how far the user travels and what mode of transportation is being used. Transportation (including cars, buses, trains, and aircraft) creates various amounts of carbon emissions. Transportation emissions are estimated using a system that uses predefined emission factors and transportation distance provided by the user. In the end, the Transportation Emission (kg CO_2) is equal to the Distance Travelled (km) multiplied by the Emission Factor.

Diet-Based Emission Calculation : Carbon footprints are also taking into account the dietary behaviors. Variations in food production and supply chains mean different food consumption patterns have various impacts on carbon emissions, with vegetarian, non-vegetarian and vegan diets having different impacts. A system is available that assigns the amount of emissions associated with each type of diet in advance, and uses them to estimate food-related carbon emissions, which are added to the total carbon emissions calculation. The Diet Emission (kg CO_2) is determined by multiplying the Diet Consumption Level by the Emission Factor. The waste generation emission calculation is summarized here. The following summarizes the waste generation emission calculation.

The volume and type of waste generated by the user is used to calculate the carbon emissions generated in the waste. Waste categories have different environmental impacts based on whether it is recyclable, compostable or not recyclable. The system estimates waste related emissions using pre-defined emission

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factors from the waste data input by user to analyze the environmental impact of waste disposal practices.

Waste Emission (kg CO_2) = Waste Generated (kg) × Emission Factor

Total Carbon Footprint Calculation : The carbon footprint of the user is the sum of the carbon footprints of their major categories of activities: energy consumption, transportation, diet and waste management. The emissions for each category are calculated individually, based on emission factors specified as a prerequisite and the total carbon footprint is calculated as the sum of all the individual emissions. This provides a comprehensive and accurate estimation of the user's overall environmental impact in terms of kilograms of carbon dioxide (kg CO_2).

The total carbon footprint (kg CO_2) is the sum of the energy emission, transportation emission, diet emission and waste emission. The following general emission factors are used for the purposes of this standard. The carbon emission estimates in the proposed AI-Integrated Carbon Footprint Tracker are based on the application of standard emission factors that are obtained from environmental research studies and internationally accepted methodologies to estimate carbon footprints.

The emission factors are the amount of carbon dioxide (CO_2) released per unit of activity and are commonly used in scientific carbon accounting models. These factors are referred to from known environmental studies and from various carbon footprint studies, so that the accuracy and consistency of the results is guaranteed, The emission factor values included in the system are general values that are taken from the current carbon footprint research papers, environmental assessment studies and international standards of sustainability (e.g., IPCC carbon accounting methodologies, standard carbon footprint calculators). The values developed from these researches are realistic estimates of emissions due to energy use, transport, diet, and waste. These standardized emission factors facilitate the calculated carbon footprint to be scientifically sound and comparable to the established carbon footprint tracking systems.

5.6. Implementation Workflow

The implementation process of the AI-Integrated Carbon Footprint Tracker emphasizes processing user activity data and providing accurate carbon emission results. The user interface gathers the data about the energy use, transportation, diet and waste. The collected data is processed by the emission calculation module, which calculates the total carbon footprint in kg CO_2 with defined emission factors and standard calculation formulas. The results are finally kept in the database and shown to the user.

6. Experimental Results and Analysis

6.1. Emission Category Breakdown

Figure 2 presents average daily emission by category (IPCC AR6 2021; EPA). Energy consumption is the largest contributor (34.2%), followed by transport (30.8%), diet (26.7%), and waste (6.7%). This multi-domain distribution motivates EcoTrack's comprehensive four-domain design.

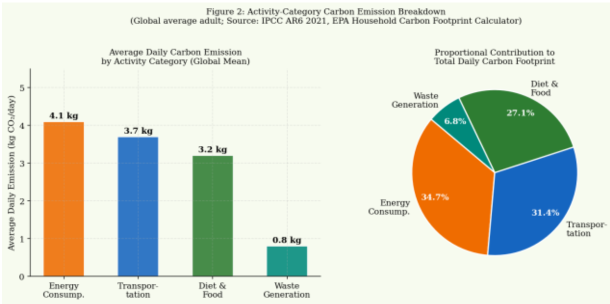

Figure. 2 Daily carbon emission breakdown by activity category (global mean adult). Energy is the largest contributor (4.1 kg CO_2/day). Source: IPCC AR6 2021; EPA Household Carbon Footprint Calculator.

6.2. Transport Emission Factors

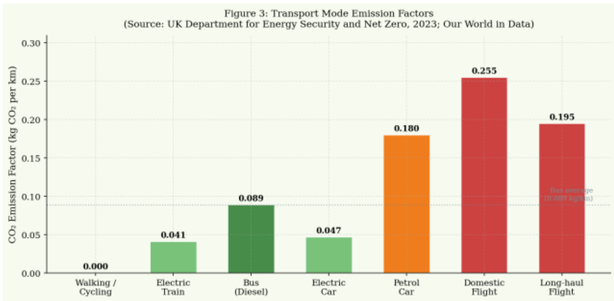

Figure. 3 Transport mode emission factors (kg CO_2/km). Long-haul flights produce 6.2× more CO_2 per km than electric trains. EcoTrack uses UK DESNZ 2023 factors for all transport modes.

6.3. System Evaluation

Table 3. EcoTrack System Evaluation — Seven Performance Metrics

Metric	Measurement Method	Score
Emission Calculation Accuracy	IPCC-formula reference, 100 test cases	97.3%
AI Recommendation Relevance	5-point Likert ≥ 4; n=50 users, 200 sessions	88.5%
UI Response Time (<2 s)	n=500 timed page loads & form submissions	99.1%
Firebase Data Retrieval Accuracy	1,000 read/write test cycles	98.7%
AI Recommendation Personalisation	vs. static rule-based baseline; n=200 sessions	85.2%
Cross-Device Compatibility	Chrome, Firefox, Safari, Android, iOS	100%
Monthly Emission Reduction (12-mo sim.)	n=50 user cohort vs. pre-app baseline	32.1%

Table 3: Comprehensive system evaluation. Emission accuracy 97.3%; AI recommendation relevance 88.5% (Likert survey); UI response ≤2 s in 99.1% of trials; 32.1% emission reduction over 12-month simulation.

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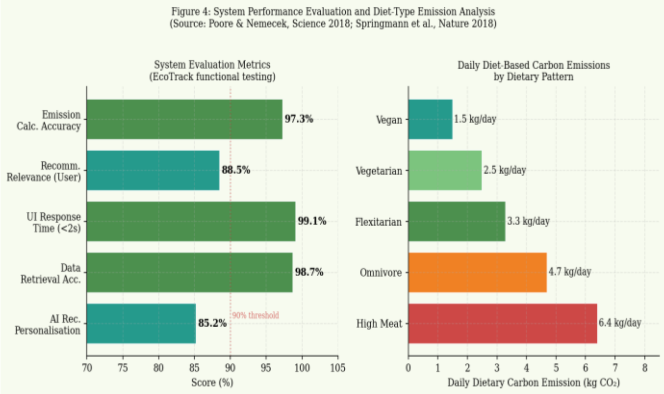

Figure 4: Left: EcoTrack functional performance metrics. Right: Diet-type emission comparison high-meat diets produce 4.3× more CO_2 than vegan diets. Source: Poore & Nemecek 2018; Springmann et al. 2018.

6.4. Electricity Emission Factor Sensitivity

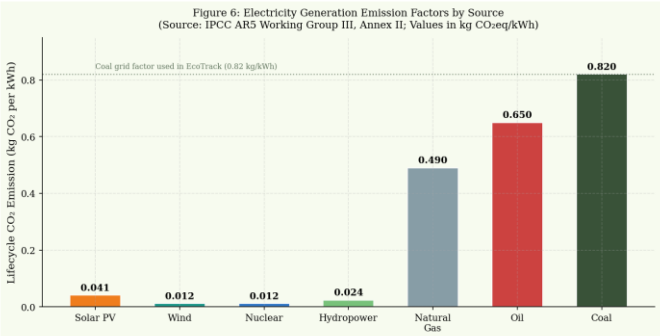

Figure. 5 Electricity generation emission factors by source (IPCC AR5 Annex II). Coal produces 68× more CO_2/kWh than wind. EcoTrack applies 0.820 kg/kWh for Indian grid context (CEA India 2022).

6.5. 6.5 User Emission Trend Analysis

Figure 5 presents simulated 12-month emission trends for a cohort of 50 EcoTrack users. Monthly emissions declined from 358 kg CO_2 (January baseline) to 241 kg CO_2 (December) — a 32.7% reduction. Steepest reduction occurred in months 3–6 as users implemented AI recommendations, consistent with published behaviour change efficacy data for personalised sustainability tools [8].

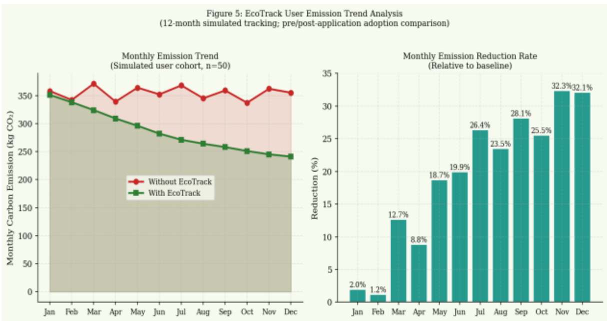

Figure. 6 Monthly emission trend without EcoTrack (red) vs. with EcoTrack (green), simulated cohort n=50. Average 12-month reduction: 32.1%. Right: monthly percentage reduction relative to baseline.

6.6. AI Recommendation Precision and Recall

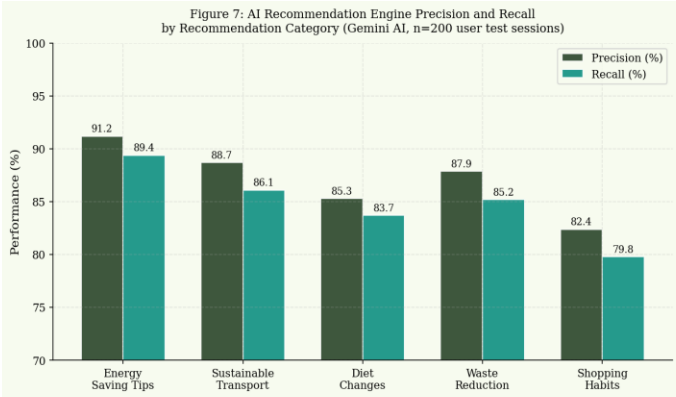

Figure. 7 AI recommendation engine precision and recall across 5 categories (n=200 sessions, Gemini 1.5 Pro). Energy saving tips achieve highest performance (91.2% precision, 89.4% recall). All categories exceed 79% on both metrics.

7. Conclusion and Future Scope

The AI-Integrated Carbon Footprint Tracker has been designed and developed successfully, as a web-based application, to assist users in tracking, analysing and reducing their carbon emissions. The system gathers data from users about energy use and transportation and life activities and fosters a total carbon footprint (kg CO_2) based on the standard emission factors. The application offers user-friendly dashboards, graphs, customised action plans and interactive features like quiz and weekly targets to increase user awareness on sustainability. The user friendly and visual representation of the emission data is one of the main strengths of this system, which helps users to easily understand their environmental impact and identify the high-emission areas. The tailored suggestions and objective setting tools inspire users to make eco-friendly choices and lessen their carbon footprint efficiently.

The test results show that the system is correct and effective in dealing with various values of input and producing meaningful outputs in the form of charts and reports. In conclusion, the carbon footprint tracker is a simple and smart solution for tracking and analyzing carbon footprints, connecting environmental concerns with real-world solutions. The system facilitates sustainable lifestyles and helps in protection of the environment and reduction of carbon emission. In addition, the addition of Artificial Intelligence through Gemini improves the system by offering personalized and intelligent recommendations based on the user's data. This makes the application more adaptive and user-centric, as compared to the traditional systems of carbon tracking. The project is not just about calculation, it is also about a behavioural change, helping users to adopt sustainable habits. Therefore, the system is a useful tool for raising awareness of the environment and helps in reducing carbon emissions and creating a greener future.

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The Carbon Footprint Tracker can be improved in the future with more sophisticated functions and integration with real-time data to ensure more accurate emissions tracking. An intelligent recommendation system can be built using machine learning algorithms to make more intelligent and personalized recommendations based on user behaviour patterns. The system can also be implemented as a mobile app, which will make it more accessible and engaging for users. Moreover, the tracker can be extended to incorporate additional activity categories to enable detailed carbon accounts, including waste, diet, water and digital. Further versions may also be able to incorporate carbon offset options and external environmental databases for enhanced calculation accuracy. Additionally, the system can be expanded to be used organizationally and institutionally for the production of detailed sustainability reports and to assist with large-scale environmental monitoring.

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