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Ecotrack - Personal Carbon Footprint Tracker

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Abstract

To combat climate change, people must monitor and reduce their carbon footprints. Carbon footprint calculators that are already available do not provide continual engagement or motivation to make behavioral changes. EcoTrack is a full-stack sustainability platform using an interactive and gamified approach for measuring and minimizing one's personal carbon footprint. The EcoTrack system is built using the MERN stack (MongoDB; Express.js; React.js; and Node.js) and collects data from the user, measures carbon emissions based on daily activities (transportation; energy usage; and lifestyle), and produces a CO_2 output for each user's activities by utilizing standard emission factors through a carbon footprint calculation engine. EcoTrack also has gamification features (i.e., leaderboard, community groups, and a token-based incentive system) that add to user engagement while encouraging users to reduce their carbon footprints. Eco Track utilizes data visualization tools to show the user various trends and patterns in the user's behavior and its impact on the users' carbon footprint. The experimental findings indicate that EcoTrack has been able to increase user engagement and has resulted in a measurable reduction in high-carbon activities over time. Ultimately, EcoTrack illustrates how gamification combined with real-time tracking can create sustainable behaviors and increase environmental awareness.

Introduction

One of the primary causes of climate change is the high amount of carbon dioxide released into the atmosphere due to the following human activities: transportation, consumption of electricity, and development of industries. Increased carbon dioxide (CO_2) is the major greenhouse gas that has led to global warming and environmental deterioration. CO_2 levels have continued to increase which has caused greater climate instability, increased global temperatures, increased melting of glaciers, and the increased occurrence of extreme weather events [1], [2]. Governments, researchers, and environmental organisations are increasingly searching for sustainable alternatives for reducing carbon emissions and encouraging environmentally sound behaviours by individuals and communities [3], [4].

Carbon Footprint is one of the building blocks of Sustainability. It refers to the total greenhouse gas emissions; both direct and indirect, created by human activity. Activities that are done every day such as driving a vehicle, using electricity, patterns of food consumption and also lifestyle choices all greatly contribute to an individual's Carbon Footprint [5], [6]. While awareness of making environmentally sustainable choices has increased, most individuals are still unaware of the actual

environmental footprint of their daily activity because they lack access to convenient and user-friendly tools that track their Carbon Footprint. Therefore, providing a way for individuals to track and comprehend their individual Carbon Emissions is an essential part of promoting Sustainable Living. There are many websites and carbon footprint calculators that can be used to estimate a user's personal emissions based on user-provided data for transportation, energy use and lifestyle choices; [8], [9] These systems usually use emission factor databases to provide an estimate of how much carbon dioxide would be produced from a user's activities, as well as recommend ways to reduce their environmental impact; [10] However, there are several issues with existing carbon tracking solutions that limit their effectiveness Most provide a static or one-off calculation, rather than continue to provide real-time monitoring and feedback [11]. Most also do not have interactive components that would support long-term engagement with users, which makes them less effective at influencing sustainable behaviour change. [12]

Recent research suggests that incorporating gamification techniques (e.g., reward systems, badges, leaderboards, social interaction) into sustainability initiatives can increase user participation and engagement substantially [13], [14]. Through gamification, motivation is added which leads to the incremental adoption of environmentally-friendly habits and the maintenance of long-term, consistent behavior change by users [15]. Additionally, community-based sustainability platforms that provide users with the ability to benchmark their own environmental performance against others create additional motivation and awareness among users [16].

Modern web technologies have evolved to such a level that developers now have the ability to create scalable, interactive applications with real-time tracking of environmental data. The "MERN stack" (MongoDB, Express.js, React.js, and Node.js) has become one of the most popular full-stack development frameworks used to create dynamic, responsive web applications [17], [18]. By integrating these technologies into environmental monitoring systems, developers can provide users with continuous emission tracking, interactive dashboards, and personalized insights into their environmental practices [19].

In addition to being used to monitor emissions, incentive-based sustainability systems have received increasing attention as an effective means through which to motivate individuals toward reducing their carbon footprint. Token-based reward mechanisms provide users with a digital incentive for adopting environmentally friendly behaviors or maintaining their emissions below predefined levels [20]. These mechanisms help close the gap between individuals being aware of the environment and actually taking action to improve it by offering users concrete reward for engaging in more sustainable behaviors [21].

In this paper, we present EcoTrack, a comprehensive personal carbon footprint (CFP) tracking system that integrates real-time emission monitoring with gamification and reward-based incentive systems. Users will be able to log their daily activities related to their mode of transportation, energy usage, and lifestyle behavior and then use standard carbon emission factor databases [22] to calculate their CFP. The EcoTrack system also has powerful visualization components that will allow users to view their emissions over time and identify their behaviors that contribute to their CFP [23]. Furthermore, EcoTrack uses tokens to incentivize continued participation and encourage environmentally responsible behaviours. Users who keep their emissions below a certain threshold (as pre-defined by EcoTrack) will be awarded with tokens that can then be redeemed for things like planting trees or discounts on sustainable goods [24]. In this way, EcoTrack seeks to integrate environmental monitoring and social interaction with an incentive system to make carbon reduction an engaging and habitual behaviour for consumers [25].

The rest of this paper is organised into the following structure: Section II presents a literature review of carbon footprint monitoring systems; Section III describes the proposed methodology and system architecture; Section IV discusses implementation details of the EcoTrack platform; Section V provides experimental results and discussion; and Section VI presents the conclusions drawn from this research and directions for future work.

Literature Survey

Many researchers have been researching how digital technologies can monitor and manage our carbon emissions. The early work on carbon footprint calculators looked at measuring the greenhouse gases caused by daily living – such as our travel habits, energy use in the home, and food choices. Mulrow et al. looked at several different types of online carbon footprint calculators and found them useful in helping consumers understand their impact on the environment; however, they found that many

calculators do not include any interactive features or personalized feedback [1]. Studies investigating tools designed to enhance environmental awareness have also suggested that calculators are instrumental in creating environmentally friendly behaviours by providing individuals with access to emission data [2].

Mobile and web-based applications are now becoming increasingly prevalent as a means of tracking personal carbon footprints. Dash et al. have created a mobile application intended for tracking personal emissions resulting from daily activities such as travelling, using energy in the home, and dietary choices. This work has shown that monitoring one's emissions in real time helps to raise awareness of their carbon footprint and promotes environmentally-friendly lifestyle choices [3]. A second study develops EcoTrack, an application for tracking personal carbon emission levels that provides users with the opportunity to analyse the impact of their daily activities on the environment through the provision of direct activity tracking and graphical analysis tools [4]. Both of these applications illustrate how digital tools can help close the gap between environmental awareness and action.

Several researchers have looked at the potential of full stack web applications to utilize real-time carbon emission data to monitor carbon emissions over time. One such web developer is Sharma et al, who developed a smart web-based carbon footprint tracker which tracks user activities such as movement, household energy use and waste and converts these into emission values based on pre-established emission factors and, therefore, predicts the emissions that will be generated as a result of each user's activity [5]. There are also other web-based platforms that support sustainability practices that have demonstrated, through the combination of interactive dashboards and environmental analytics, an increase in user interaction and decision-making [6].

Gamification is another promising avenue for encouraging individuals and communities to participate in environmentally conscious actions. Increasing the number of gamified features (points, leaderboards, challenges and rewards) has been shown to substantially increase user engagement and participation in sustainability programs [7]. Additionally, studies of gamified applications and sustainability have indicated that the incorporation of game-like features can motivate users to engage in sustainable behaviours and create long-term engagement with sustainable behaviours [8]. A systematic review of gamification and sustainability conducted by Zhang et al., found that behavioral incentives were a key factor in encouraging green transportation and increasing climate change awareness [9].

Behavioral Change Apps for Environmental Sustainability Researchers have explored the efficacy of behavior-change apps (apps for changing a person's behavior) on the long-term impacts of reducing carbon footprint. One study by Wemyss et al. reported that behavior change applications are effective in helping to reduce carbon emissions, as long as the application actively engages users and gives meaningful feedback on a continuing basis [10].

Some studies of smart energy applications indicate that real-time monitoring systems can use real-time feedback to make users more aware of how they consume electricity, which can lead to users reducing their usage through an increase in awareness of their own energy consumption patterns [11].

Gamified Energy Management The concept of gamifying energy management systems has been examined in past research. Avila et al. developed a gamification-based energy management application that is designed to use adaptive algorithms to track the overall energy consumption levels of users and to provide motivational incentives for users to reduce their energy consumption [12]. Findings indicate that combining technology and behavioral science can impact consumer behavior positively and encourage sustainable behavior.

Several Psychological as well as technological aspects can impact how people choose whether or not to use carbon footprint apps. Research indicates that users will adopt these types of apps if they feel they will receive real value, the app is easy to use, and the app has a social benefit [13]. Additionally, various studies have shown that users are more likely to participate in environmentally friendly activities when they use a digital platform that allows them to socially interact with others, earn rewards for participating in environmentally friendly activities and learn about sustainable practices [14].

Within the last few years' new AI-enabled sustainability applications have begun being created that allow businesses and individuals to monitor and analyze their behavior to recommend ways to reduce their impact on the environment based on commonalities found through the analysis of individual behaviours. An example of this work by Jasmy et al. describes a smart system that monitors personal carbon footprints (the amount of carbon produced by an individual's lifestyle)

and recommends ways to reduce that footprint using machine learning techniques to analyses data about user behavior to discover reoccurring patterns [15]; while others have developed AI-based tools that assist users with estimating the amount of carbon that they produce based on their consumption habits through advanced data analytic techniques [16].

Community-led sustainability platforms represent an additional area of research worth exploring. Research indicates that adding social networking features, such as group challenges and community leaderboards, may encourage individuals to help with time-based environmental challenges [17]. As well, there is evidence that sharing progress and comparing one's results to those of others leads to increased retention and engagement among users of sustainability platforms [18].

There have also been a number of experimental studies conducted in order to evaluate the impact of using a carbon tracking application on a user's behavior in "real life." Enlund et al. observed that people reduced their carbon footprint approximately by 10% within weeks of downloading a carbon calculator application into their devices [19]. Similarly, research regarding sustainability applications based on smart phones suggests that digital tools can be used for tracking how behavior changes related to both transportation and diet [20]. Recent advances in carbon footprint tracking systems have included the addition of environment [21]. Using techniques such as graphs, charts, and emission indicators to visualize data has been shown to be effective for communicating complex environmental data to users [22].

In addition to developing individual tracking systems, numerous research studies have explored the integration of carbon monitoring into larger environmental sustainability frameworks. For instance, CarbonKit has developed an all-encompassing platform that combines personal carbon tracking with incentive mechanisms and social interaction to encourage users to adopt sustainable living practices [23]. Other studies have shown that combining economic incentives with environmental monitoring can greatly enhance participation in sustainability programs [24].

There has been further investigation into the use of gamified platforms for providing sustainability education recently. The current work by Novo and others examined an internet-based application that teaches users about sustainability through gamification, resulting in significant, positive shifts in participants to act in a more environmentally-friendly way [25]. The results of this work are promising and indicate how education, technology, and the science of behavior can all work together to help tackle issues related to climate change.

Even though modern carbon footprint tracking devices have been developed to monitor carbon footprints more accurately than ever, there are still limitations with these existing solutions. For example, many of these applications only calculate static carbon emissions, rather than providing real-time or longitudinal data points to keep people engaged long after they initially determine their emissions [26]. Additionally, many of the applications currently available do not utilize advanced analytics and personalization capabilities; therefore, their ability to deliver sustainable behaviors is diminished [27]. Consequently, researchers are calling for an integrated system that combines on-going carbon footprint monitoring, visual representation, and incentives for changing behavior [28].

Modern sustainability platforms seek to solve some of the limitations of today's technology through the use of many different types of technologies, like real-time data tracking, gamification, social interaction and tokenized reward systems. The combination of all these technologies allows us to create an exciting, fun and addictive way to monitor our environment [29]. The EcoTrack platform is built on current research that integrates carbon emissions monitoring with a gamified reward system, a social leaderboard and advanced data visualization to inspire users to live sustainably [30]

sophisticated analytics and personalization capabilities

Proposed System Architecture

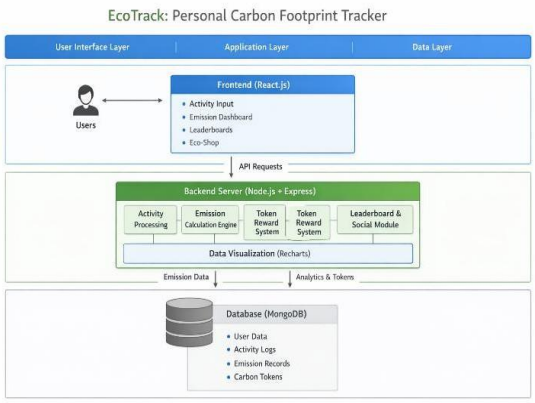

Figure 1. System Architecture

The EcoTrack system was designed in a three-layer architecture using the MERN stack. The EcoTrack system allows users to track their

daily carbon emissions, understand their impact on the environment, and earn rewards for making sustainable choices. The EcoTrack system architecture includes three layers: User Interface Layer, Application Layer, and Data Layer. The User Interface Layer is responsible for displaying user activity data and calculating carbon emissions, while the Application Layer processes the data to generate insight.

1. User Interface Layer

The User Interface Layer provides the front end of the EcoTrack system, which allows users to interact with the EcoTrack system. It was built using React.js to allow users to have a dynamic and responsive user experience.

In the User Interface Layer, users can perform a variety of actions, including:

Entering daily activities such as distance travelled by car, kilowatts of electricity used, and habits.

Viewing carbon footprint statistics through an emissions dashboard.

Viewing their individual standings on the community leaderboards.

Accessing the Eco-Shop to redeem their carbon tokens.

In addition, the frontend of ECOTRACK sends the user-supplied data to the back end through API requests for processing and analysis.

2. Application Layer

The EcoTrack system's application layer is the primary component that processes transactions and communicates with users, the database, and the logic of processing transactions. Node.js and Express.js are the technologies that power the application layer, and they manage all of the data processing. The application layer is made up of several components, including but not limited to the following:

- Activity Processing Module: The activity processing module receives activity data from users, validates the data, and then processes the data.

- Carbon Emission Calculation Engine: The carbon emission calculation engine converts the activity data sent by users to generate carbon emission values based on predefined emission factors. For example, if a user reports a certain distance traveled in their vehicle or the number of kilowatt hours of energy used, those numbers could be multiplied by an emission factor to calculate how many kilograms of carbon dioxide will be emitted from that activity.

- Token Reward System: The token reward system generates carbon tokens for users whose monthly carbon emissions fall below their predefined monthly limit. The token reward system incentivizes users to engage in environmentally friendly activities by rewarding them for their environmentally responsible behaviours.

- Leaderboard & Social Module: The leaderboard & social module ranks EcoTrack users according to their EcoScores, and it allows EcoTrack users to compare their relative levels of environmental performance with other EcoTrack users. By providing this social interaction, the leaderboard and social module provide incentives for users to reduce their carbon footprint.

3. Data Store

System data for the Data Layer is held in a MongoDB database. A major reason we chose MongoDB is that it can look up large amounts of user activity logs and provide real-time updates quickly.

The Data Layer contains the following information:

- Details about User Accounts
- Daily User Activity Logs
- Carbon Emission Reporting
- Eco-scores and Leaderboard Ranking
- Carbon Token Balance
- Eco-Shop Transaction Information
- When users ask for analytic information or perform an action in the system, the backend will access this database.

4. System Data Flow

The system's process is sequential:

Enter / Grab a user's activity data using the React frontend. API send data from the frontend to the Node.js/Express backend.

Process the entered user data using the carbon footprint calculation engine.

Store calculated carbon emissions data and activity logs in MongoDB.

Generate analytics, dashboard, and leaderboard outputs. Carbon tokens will be created by the token reward system if the calculated carbon emissions are lower than the threshold.

Show the results (data) to the user via interactive charts and dashboards.

5. The Proposed Architecture has Many Advantages.

There are a number of benefits to using the proposed architecture:

1. The use of MERN stack technologies provides the ability to create a scalable system.
2. Real-time emissions metrics and analytics are available through the system.

3. The User Interface provides an interactive Web-based tool with visual dashboards.
4. Users can earn rewards in the form of tokens and be represented on a leaderboard to encourage them to be more sustainable.
5. Data will be stored in and managed by MongoDB in an efficient manner.
6. Through this architecture, we will provide an efficient and engaging EcoTrack platform that encourages users to monitor their carbon emissions and participate in sustainable living.

Methodology

1. Data Collection

Stage One — Information Gathering: the proposed EcoTrack system will first involve measuring the daily consumption habits of an individual user, who has recorded Carbon emissions through transportation, energy consumption, or lifestyle choices.

The EcoTrack system enables users to enter transport data, energy consumption data, and lifestyle data into a web-based data entry application developed by the EcoTrack Company using React.js. These three habits are typically the largest contributors to an individual's daily carbon footprint, so having a reliable record of how an individual has consumed these three types of activities will provide valuable information. Once an individual has entered their consumption activities into the EcoTrack system, this data will be sent from the web-based application to a cloud-based backend server using API calls. The backend server is then able to validate the user-entered activity record for accuracy and completeness before storing it in a database. This provides a complete, comprehensive, and reliable historical record of the user's activities that can be accessed later to calculate the user's carbon emissions and conduct environmental assessments.

2. Carbon Emission Measurement

Once users have recorded their activities, the EcoTrack system determines the total carbon emissions resulting from all user activity. This calculation uses standardized, science-based emission factors that represent the quantity of carbon dioxide emitted for each unit of activity. As an example, your transportation emission will be calculated by taking the distance you've travelled and multiplying it with the emission factor for your mode of transportation. Similarly, your electricity consumption will be converted to CO2 emissions using standard energy emission coefficients. By multiplying the value of your activity by the appropriate emission factor, EcoTrack calculates your total carbon footprint. EcoTrack then stores your emission results in its database so that they can be further analysed and visualized.

3. Token-Based Reward System

In order to promote and encourage environmentally responsible behavior among its users, the EcoTrack system has developed a token-based reward system. Each registered user of the EcoTrack system has been assigned a carbon emission limit or sustainability target that is predetermined by the EcoTrack system. This limit is continuously compared by the system to the total emissions of each user. If a user keeps his/her emissions within the permitted emission limit, then the EcoTrack system rewards him/her with digital carbon tokens for each period in which the user has kept his/her carbon emissions below the allowed limits. These digital tokens are an incentive for users to reduce their carbon emissions and to continue engaging in sustainable living. By providing a token-based reward program, EcoTrack is able to make environmental consciousness an activity and to create a motivating environment for people to become environmentally conscious.

4. Social Interactivity and the Leaderboard

The EcoTrack platform also contains social features that increase user interaction and user activity. A leaderboard is used to rank users according to their environmental performance, with a score called the Eco-Score. This score is calculated from the user's carbon emissions and their achievements in sustainable living. Users can compare their rank against other users, and they can see how their rank compares to that of other users in the community. The leaderboard creates a competitive and collaborative atmosphere in which users will try to enhance their environmental performance while taking advantage of sustainability challenges.

5. Using visual analytics and analytical tools to review carbon emissions

Using carbon emissions data in numeric format is sometimes difficult to interpret; therefore, the EcoTrack system's incorporation of visual analytics enables users to quickly and easily generate meaningful insights about their activities and the environment. The system leverages visualization libraries (e.g., Recharts) to produce graphical representation of emission data via emission breakdown charts, weekly emission trend charts, and carbon usage

indicators. These visual tools provide the capability for users to easily identify activity patterns and identify those behaviours that contribute to the users overall carbon footprint. Having the ability to evaluate these analytics provides users with information necessary to make better decisions concerning emissions reduction.

6. Data Storage and Management

Data generated through EcoTrack is stored in MongoDB and includes user profiles, activity logs, calculations of emissions, balance of tokens, and rankings on leaderboards. MongoDB is chosen because it can handle large amounts of both structured and semi-structured data created by user activity efficiently. The architecture of the database ensures that data is securely stored and can be accessed or updated in real-time, enabling the platform to provide users with accurate emissions information and sustainable living insights.

7. System Workflow

The entire EcoTrack system operates within a set workflow process. Users begin the process of entering their activities at the web interface where they complete their daily activities (e.g., how many times did I walk today). This data will then be transmitted to the back-end server for validation and processing. The carbon emissions engine will then convert the activities into emissions by using pre-defined emission factors (which can be found in the Carbon Emissions Engine section). The emissions created from the process will then be stored in a central database, where the emissions can then be analyzed to see if the user's total emissions are below the established threshold (i.e., did I meet the target goal). If they are below the established threshold, carbon tokens will be generated for the user (as a reward). Finally, users will be able to view their current and total historical records using an interactive dashboard, which will also include a chart representation of their historical emissions and environmental data, and monitor their progress towards improving their environmental behavior.

Result

The proposed EcoTrack – Personal Carbon Footprint Tracker application was implemented as a full stack web app using the MERN Stack, and the system was tested through logging activities of users such as using transportation, using energy, consuming food, and shopping. Results from testing indicated that the system successfully tracks carbon emission, provides visual analytics for users, and encourages users to take steps to reduce their impact on the environment through rewards and gamification.

The dashboard provides a real-time overview of carbon emissions and sustainability performance. When tested, the monthly emission recorded by the system was 260.7 kg CO_2e out of a maximum limit of 500 kg – the daily emission was 5.0 kg CO_2e (29% of the daily limit), meaning the user stayed within a sustainable range.

From an overall category analysis, carbon emissions from food consumption were by far the most significant contributor to overall emissions (231.9 kg CO_2e), followed by transport (16.2 kg CO_2e) and energy usage (12.6 kg CO_2e). Through a weekly report, the total weekly emissions were recorded as 33.2 kg CO_2e and averaged 4.74 kg per day, which all remained under defined emission thresholds.

In addition to providing personal recommendations, the system utilizes a token-based reward system as well as a leaderboard to encourage users to engage in responsible behaviours. Tokens earned through the reward system can be redeemed in the Eco-Rewards Shop for environmental programs or sustainable incentives.

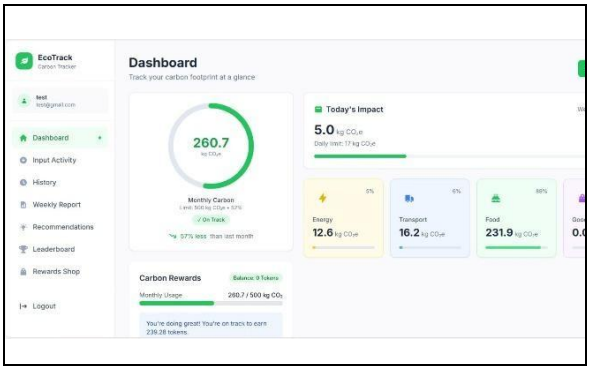

Figure 2: EcoTrack Dashboard Interface

The main user interface for EcoTrack is shown in this figure with a monthly overview of carbon emissions, daily impact, and distribution breakdown by categories.

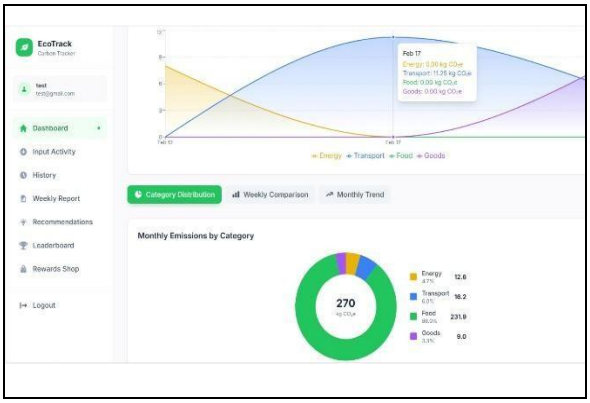

Figure 3: Carbon Emission Trend Analysis

In this illustration, a weekly breakdown of carbon emissions by categories of energy, transportation, food, and goods shows trends for how they affect carbon emissions.

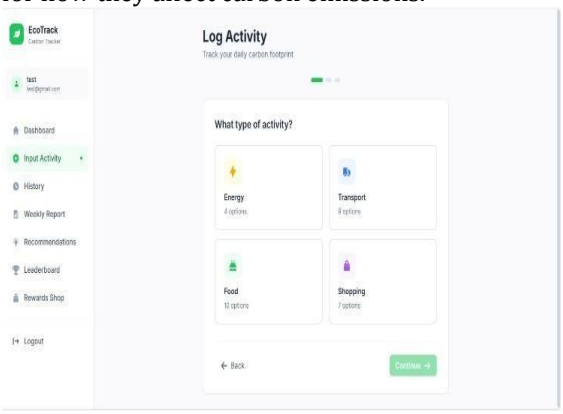

Figure 4: Activity Logging Interface

An interactive page within the ecoTrack allows users to log their daily activity from energy usage, transportation methods, food consumption, and shopping activities.

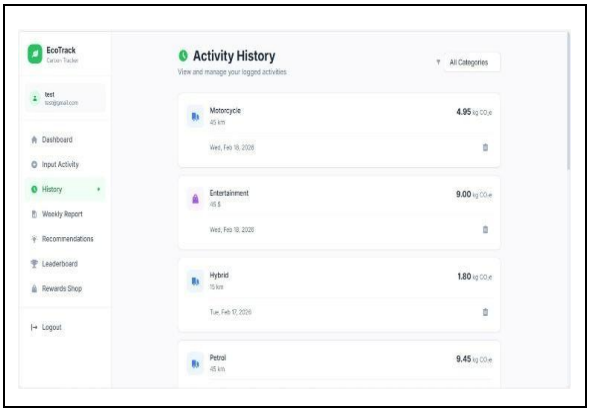

Figure 5: Activity History Track

This graph displays all previous logged activities and their corresponding calculated carbon emissions.

Figure 6: Weekly Carbon Emission Report

The weekly summary is illustrated with carbon emissions, average daily and total carbon emissions, and other information and recommendations for sustainability.

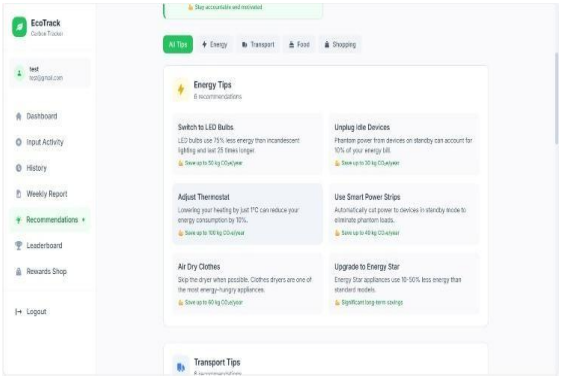

Figure 7: Sustainability Recommendation System

Users receive sustainability and carbon reduction recommendations from the system based on their recorded activity.

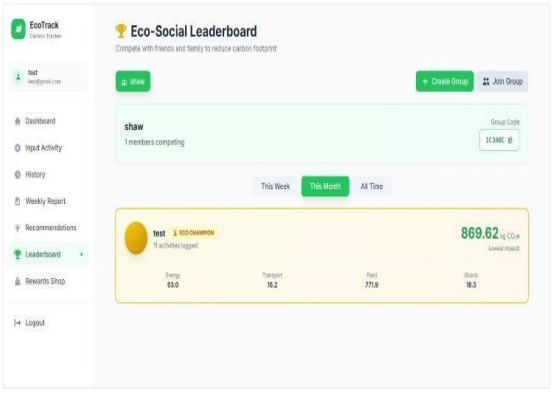

Figure 8: Eco-Social Leaderboard

Users can compare their carbon emission performance with other users in the community on the eco-social leader board.

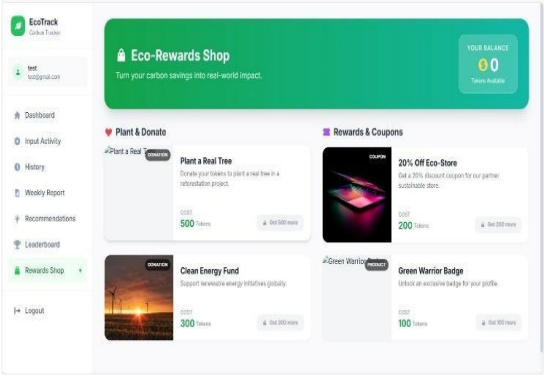

Figure 9: Eco-Rewards Shop Interface

Users can redeem earned rewards from their carbon reduction through the eco-rewards shop with the help of the eco-rewards system.

Conclusion

EcoTrack is a personal carbon footprint tracker created using the MERN technology stack.

EcoTrack allows its users to log their daily activities including travel, energy consumption, food intake, and shopping activities to calculate their carbon emissions. EcoTrack gives users the ability to view their emissions in real time, visualize their emissions data, and receive category-specific analyses of their emissions to help them comprehend and control their impact on the environment. EcoTrack also encourages users to adopt environmentally friendly behaviours through leaderboards and reward tokens. In conclusion, EcoTrack presents an innovative way of promoting environmental sustainability and awareness through the combination of carbon tracking, data visualization and gamification within a simple-to-use application.

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