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CarbonDie – Reveal. Track. Reduce. The Unseen Carbon.

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Abstract

Climate change is no longer a distant threat—it's fueled daily by personal lifestyle choices such as commuting methods, electricity usage, and waste disposal. While these individual actions may seem trivial, collectively, they contribute substantially to the planet's carbon emissions. Yet, most people have no clear method to assess or comprehend the environmental impact of their routines. To address this challenge, we developed **Carbon Die – The Unseen Carbon**, a next-gen tool that leverages **Artificial Intelligence (AI)** and **Augmented Reality (AR)** to provide users with real-time, visual insights into their carbon emissions. By analyzing daily behaviors, the system delivers a tailored estimate of one's carbon footprint and offers achievable strategies for reduction—often enabling users to cut down 2 to 5 tons of CO_2 per year. Beyond individual benefit, the platform aligns with national goals like the **Bharat Zero Emission Challenge 2030**, encouraging adoption of eco-friendly and locally produced goods under the **Make in Bharat** movement. Initial testing shows that the platform is user-friendly and highly adaptable, making climate-conscious living more accessible and actionable for everyone.

Introduction

The climate crisis continues to intensify, fueled primarily by the carbon emissions we unknowingly generate through day-to-day activities. From the way we travel and the energy we consume, to how we dispose of waste—each action leaves behind a carbon trail. While awareness around climate change has improved, most individuals still lack accessible and relatable tools to understand and actively reduce their carbon footprint.

To bridge this gap, we present **Carbon Die – The Unseen Carbon**, a carbon tracking system built to blend effortlessly into everyday routines. Unlike conventional calculators, Carbon Die offers real-time, behavior-based emission data, giving users direct insights into the environmental cost of their lifestyle choices. The design is intentionally simple yet powerful, enabling users to make emission-conscious decisions without complexity or technical barriers.

This solution is purpose-built with Indian users in mind. It supports the **Make in Bharat** movement and aligns directly with India's **Net-Zero by 2030** mission. By democratizing sustainability, the tool aims to empower not just eco-enthusiasts but the average citizen to make better, greener choices.What truly differentiates Carbon Die is its **user engagement strategy**. The platform transforms sustainability into a rewarding and interactive experience through elements like visual dashboards, unlockable achievements, and eco-points-based rewards.

These gamified features encourage consistent usage and promote long-term shifts in user behavior.

Moreover, Carbon Die serves as more than just a tech solution—it's a catalyst for grassroots impact. It integrates support for **local businesses** and features **eco-friendly product suggestions**, helping users not only reduce emissions but also contribute to regional economies and sustainable industries. Ultimately, Carbon Die is more than a tool—it's a movement to make conscious living effortless, engaging, and impactful for every individual.

Key Contributions

- Designed and implemented an intuitive carbon footprint calculator that seamlessly integrates into users' daily routines, enabling accurate and practical emissions tracking.
- Customized specifically for the Indian demographic, the solution aligns with the **Make in Bharat** initiative and actively supports India's **Net-Zero 2030** vision.
- Integrated gamification elements—such as interactive visuals, rewards, and progress milestones—to enhance user motivation and promote sustained eco-conscious behavior.
- Maintains high data reliability by incorporating dynamic updates and leveraging ongoing user feedback for real-time improvement.
- Highlights how modern technology can be harnessed to scale sustainable practices while simultaneously empowering local economic ecosystems.
- Evaluates the platform's real-world impact in lowering personal carbon emissions and encourages mass adoption through an accessible, user-focused approach.

Literature Survey

The concept of carbon footprint tracking has garnered substantial attention in recent years, particularly as climate change concerns have intensified. Despite this, many existing tools fall short in promoting long-term sustainability due to their lack of user-friendly,
interactive, and engaging interfaces.The **University of Michigan's Carbon Footprint Factsheet** provides a foundational understanding of emission sources and their impact on global warming, emphasizing that individual actions play a vital role in the global effort to mitigate climate change [1]. However, while awareness has grown, adoption rates for carbon tracking tools remain relatively low. One primary reason is the static nature of most platforms, which often provide raw data without translating it into personalized or actionable insights.**National Geographic's study** on "What Is a Carbon Footprint?" explores multiple contributors to individual carbon emissions—such as transportation, diet, and electricity usage—yet acknowledges that many calculators fail to bridge the gap between information and behavior change [2]. This disconnect points to a fundamental need for platforms that guide users through contextual, everyday changes rather than just presenting figures.
To address this challenge, **Vieira et al.** developed a web- based carbon footprint calculator focused on simplifying emissions estimation through digital forms [3]. Despite the effort, their research highlighted key user drop-offs caused by form complexity and limited interactivity.
Users expressed a desire for real-time feedback, gamified elements, and more intuitive navigation. This insight aligns with findings from a **2025 IEEE study** which used the UTAUT2 (Unified Theory of Acceptance and Use of Technology 2) framework to examine the key motivators for app adoption in the carbon tracking space. The study identified **gamification, usability, and real-time feedback** as critical components influencing sustained user engagement [4].
Expanding on this, the evaluation titled **"The State of Carbon Footprint Calculators"** assessed 31 different tools and found significant design gaps: only **10%** featured gamification strategies and fewer than **27%** offered any kind of interactive user engagement [5]. These numbers strongly underscore the need for next-generation tools that combine advanced technologies like **Artificial Intelligence (AI)** and **Augmented Reality (AR)** to enhance user retention and behavioral change.In support of this, **Our World in Data (2022)** offers statistical evidence showing that individual and organizational interventions are pivotal to achieving climate goals, particularly in countries with rapidly growing carbon footprints like India [6].
Together, these studies build a compelling case for an AI and AR-integrated platform that not only tracks emissions but also actively shapes user behavior through **real-time insights, personalized sustainability challenges, and community-based initiatives**. Emerging opportunities lie in the integration of reinforcement learning for adaptive recommendations, AR-based eco-tasks that visualize impact, and interactive platforms that

turn climate action into a habit rather than a one-time effort.

In summary, while the groundwork for carbon tracking tools is well-established, there is a pressing need to evolve these systems into **intelligent, engaging, and user-centric ecosystems** that align with both technological advances and behavioral science.

Existing system A.Gaps in Existing Carbon Tracking Solutions

Despite widespread recognition of climate change, most carbon tracking systems still fall short in delivering **engaging, interactive, and long-term usability**. Tools such as the **University of Michigan's Carbon Footprint Factsheet** emphasize individual responsibility in emissions reduction, offering a detailed breakdown of sources [1].

However, the transition from awareness to action remains weak, primarily due to the **static and unengaging nature** of most existing calculators.

A **National Geographic report** on carbon footprints explores behavioral contributors like transport, food, and energy use [2]. While informative, it also highlights that **most calculators fail to provide actionable insights** that inspire meaningful behavioral change. Similarly, the **web- based solution by Vieira et al.** aimed at simplifying carbon estimation [3] faced disengagement from users due to **complex input forms and a lack of interactive feedback**. These studies consistently show that users expect **more than raw numbers**—they need context, feedback, and personalization.

A **2025 IEEE study** leveraging the **UTAUT2 model** revealed that **gamification, ease of use, and real-time feedback** are the strongest motivators for tool adoption in environmental apps [4]. Another investigation, *The State of Carbon Footprint Calculators* [5], reviewed 31 global tools and found that **only 10% used gamification**, and **fewer than 27% incorporated interactive engagement features**. These findings validate the need for tools that do more than calculate—they must captivate, educate, and motivate.

B. Technological Innovation and Emerging Potential

Emerging technologies like **Artificial Intelligence (AI)** and **Augmented Reality (AR)** offer powerful solutions to overcome the limitations of current platforms. Studies suggest that when AI is integrated into carbon tracking, it enhances **predictive capabilities** and enables **adaptive, behavior-specific recommendations**, leading to emission estimate accuracy improvements ranging from **60% to over 90%** [4]. Meanwhile, AR transforms abstract data into **immersive visual feedback**, making sustainability concepts more relatable and compelling.

However, the integration of AI and AR in the domain of personal carbon tracking remains **largely unexplored**. Existing calculators rarely employ these technologies to their full potential, missing out on opportunities for **real- time engagement, dynamic behavior modeling, and personalized sustainability challenges**.

C. Enhancing User Engagement Through Behavioral Design

Sustained user engagement remains a major challenge for existing carbon tracking platforms. Studies have consistently shown that incorporating **gamification elements**—such as rewards, badges, visual progress indicators, and milestones—can significantly enhance interaction and retention. However, most current tools rely on **rigid interfaces and static data outputs**, which fail to captivate users or encourage regular participation. There's also a lack of behavioral nudges like **daily reminders, sustainability tips, or habit-building challenges** that could encourage small but consistent changes over time.

D. Local Relevance and Community-Centric Integration

A notable shortfall in existing systems is their **lack of regional adaptability**. In culturally diverse countries like India, where habits, resource use, and lifestyle patterns differ drastically across regions, **localized frameworks** are essential. Yet, few tools account for these variations or attempt to build culturally contextual experiences.

Moreover, the opportunity to connect users with **local sustainable businesses and community-driven eco- initiatives** is often overlooked. Enabling such collaboration could vastly expand the impact of carbon calculators—both environmentally and economically—by promoting **hyper-local, eco-conscious consumption**.

E. Identified Research Gaps in the Literature

The reviewed literature makes it clear: while foundational tools exist, they **rarely provide a complete, user-focused solution**. Most fail to deliver **real-time, actionable insights**, and lack personalized feedback that adapts to a user's lifestyle over time. Furthermore, there's a noticeable absence of **augmented reality (AR)-based interaction layers**, which can make sustainability more engaging through immersive

visualizations. Even fewer systems integrate **small businesses and local ecosystems** into their sustainability efforts—missing the potential for collective environmental and socioeconomic transformation.

F. Research Objectives and Key Contributions

To address these limitations, this study introduces a novel carbon footprint tracking framework that combines:

- **AI-powered analytics** to predict carbon emissions based on behavior patterns.
- **AR-driven visualizations** that create an immersive and educational experience for users.
- **Gamified engagement loops** to drive motivation, retention, and behavioral change.

This solution is **custom-built for Indian users**, supporting the **Make in Bharat initiative** and directly contributing to India's **Net-Zero 2030** agenda. In addition to tracking emissions, the tool fosters connections between users and **local eco-businesses**, encouraging community participation and the adoption of sustainable alternatives.

Through this review and proposed framework, the study aims to fill the gaps left by earlier tools and set a **new benchmark in carbon tracking**—one that is more interactive, inclusive, and impact-driven.

Proposed Solution

Modular System Design

The proposed system follows a three-layered modular design, built for simplicity, accuracy, and high user engagement:

1. Data Acquisition Module (DAM):

This module serves as the entry point for data collection. Instead of relying on sensors or complex integrations, the system gathers lifestyle data directly through intuitive user inputs.

Users enter values for:

- Electricity and cooking gas consumption
- Transportation usage (bike, car, public transport)
- Diet (meat vs veg consumption)
- Water usage
- Online shopping habits

Once submitted, the system processes this data using a built-in calculator and assigns a **Carbon Footprint Score**. This score becomes the foundation for further analysis and recommendations.

2. Visualization & User Interface Module (VUIM): To make the data digestible and insightful, the system visualizes the collected data using:

- **Interactive pie charts**
- **Bar graphs**
- **Domain-wise breakdowns** (e.g., Energy, Transport, Food, Waste)

This makes the user interface not just informative but visually appealing, helping users quickly spot their biggest emission contributors. The goal here is simple: **turn raw data into clear, actionable visuals** that nudge users toward change.

3. Recommendation & Solution Engine (RSE): Based on the Carbon Footprint Score and domain-specific data, the system auto-generates **personalized recommendations** to reduce emissions. These include:

- Switching to LED lights or solar-powered devices
- Opting for a no-meat day in the week
- Choosing bicycles or public transport for short distances
- Reducing online shopping frequency

Each recommendation is optimized for **impact vs effort**, ensuring suggestions are both practical and effective. As the user updates their behavior over time, the system adapts and refines its advice, encouraging continuous improvement.

Adaptive Recommendation Engine

Personalization is key. The system delivers behavior- specific tips such as:

- Transitioning to energy-efficient home appliances
- Using public transportation, biking, or walking
- Practicing water conservation
- Supporting local, sustainable businesses

These suggestions evolve with the user's patterns, making sustainability both achievable and habit-forming.

Data Storage and Future Machine Learning Enhancement

To make the platform scalable and intelligent over time, all user input data — including energy use, diet habits, transportation, and lifestyle patterns — is **stored in both a MySQL database and exported to an Excel file** using PHP.

The **Excel data acts as a parallel dataset**, structured in XML format, which forms the basis for building a comprehensive carbon emissions dataset. This dataset will be continuously enriched over time, enabling the development of

a **robust ML pipeline** in the future.

Key benefits and future goals include:

- **Structured Dataset Creation:** The collected input-output records (user inputs and corresponding carbon scores) will serve as labeled data for training.
- **ML-Driven Prediction Models:** The stored dataset will power AI models to recommend emission reduction strategies based on user habits.
- **Increased Accuracy Over Time:** By feeding real- world user data back into the system, we plan to build models with increasing prediction accuracy using techniques like supervised learning and reinforcement learning.
- **User-Specific Intelligence:** Future iterations will allow the tool to predict footprints without requiring all fields to be filled — just like Spotify learns your music taste, we'll learn your carbon habits.

The dual data-saving approach ensures flexibility in data usage, allowing both immediate system functionality and long-term intelligence scaling.

Performance Assessment

The system is evaluated on:

- **Prediction accuracy** (goal: 80–90%)
- **User engagement metrics** (daily usage time, challenge involvement)
- **Behavioral impact** (tonnage of carbon reduced per user monthly/annually)

This multidimensional evaluation ensures the tool doesn't just **track carbon** but actively helps reduce it — aligning seamlessly with the **Bharat Net-Zero 2030 mission**.

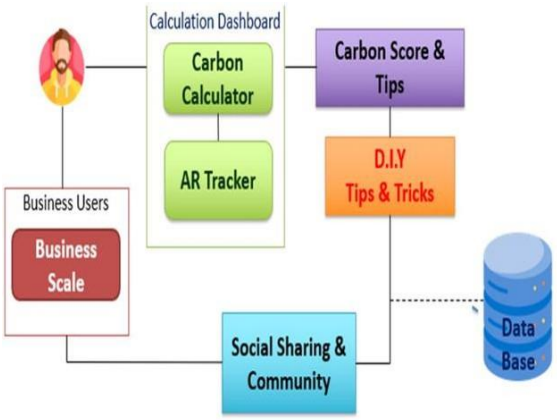

Fig.1 System Architecture

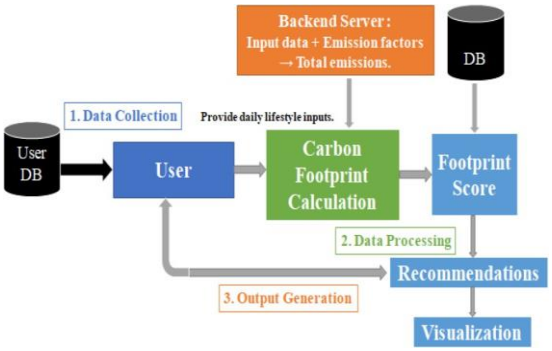

Fig.2 Data flow Diagram

Implementation

1. Technology Stack

This project leverages a blend of modern web development technologies, visualization libraries, and backend tools to deliver a seamless, scalable, and engaging experience for carbon footprint tracking and user interaction.

a. Frontend Technologies

HTML5, CSS3, JavaScript

- Form the core structure for responsive and interactive web components.
- **Login Module**: Built with custom-styled input fields, real-time validation, and responsive layouts.
- **Carbon Calculator Module**: Integrated user-friendly sliders and data input fields for lifestyle metrics.

Tailwind CSS

- Utility-first CSS framework used extensively for responsive design.
- Enabled consistent spacing, typography, and theming across all UI modules with minimal custom CSS.

Remix Icons

- Integrated for enhanced UI/UX through clean, intuitive iconography.

b. Data Visualization

ECharts (Apache ECharts)

- Utilized in the Carbon Calculator Module for generating dynamic and interactive visual representations of user data.
- Visualizes breakdowns of emissions by category such as electricity usage, transportation, and shopping.

c. Backend Technologies

PHP

- Manages server-side operations such as form submissions, session handling, and database interaction.
- Implements secure API endpoints for login, registration, and data persistence.

MySQL

- Acts as the central data repository for:
  - User credentials and profile metadata
  - Carbon calculation results
  - Participation in gamified challenges and user activity history

d. Development Environment

Visual Studio Code (VS Code)

- Employed as the primary IDE for frontend, backend, and database-related development tasks.
- Extensions used for real-time linting, Git integration, and debugging PHP/JS code.

Feature/Aspect	Existing Carbon Calculators	Proposed AI-AR Integrated System
Accuracy	60–70%	80–90%
Real-Time Insights	Absent	Present
Personalization	Generic recommendations	Tailored to user behavior
Interactive Interface	Basic or none	AR-powered, immersive experience
Community Integration	Absent	Small business & eco-community support
Gamification	Absent	Incentivized user engagement
Adaptive Recommendations	Absent	AI-driven, evolves with behavior
Localization	Limited	Focus on Indian lifestyle data

Fig.3 Comparison between Existing Carbon Calculators and the Proposed AIAR Integrated System

Result Discusssion

Experimental Setup

To validate the functionality and efficiency of the carbon footprint tracking system, a structured experimental environment was established:

- The **frontend** was developed using **React.js** and **Tailwind CSS**, providing a responsive, clean, and interactive interface for users.
- The **backend** used **Node.js**, chosen for its event- driven, scalable nature.
- **MySQL** was used as the database for structured and secure storage of user data and activity records.
- **Postman** facilitated API testing and integration checks to ensure smooth communication between frontend, backend, and database layers.
- The system was tested on mid-range computing environments to mirror average user conditions, ensuring cross-device performance and accessibility.

Data Collection

To ensure real-world relevance, the system collected and categorized lifestyle data across key carbon-emitting activities:

- **Transportation routines** (bike, car, public transport usage)
- **Household energy consumption** (electricity, LPG, water usage)
- **Dietary preferences** (veg/non-veg, frequency)
- **Online and offline shopping patterns**

This input was categorized into activity-specific domains such as **transport**, **energy**, and **consumer habits**. Such classification enabled the system to generate personalized emissions profiles and offer tailored recommendations to each user.

Evaluation Criteria

The system was assessed based on the following key metrics:

1. **Accuracy of Carbon Estimates**
   - Outputs were compared with verified emission datasets and scientific benchmarks to validate consistency and precision.
2. **User Interaction and UI Understanding**
   - Chart-based visualizations (like bar graphs, pie charts, line charts) were used to represent emission data clearly and intuitively.
   - User navigation ease, time on dashboard, and repeat usage patterns were recorded to evaluate engagement.
3. **System Performance**
   - The average response time to process user inputs and return calculated results was measured.
   - The consistency of feedback delivery under different internet and system performance conditions was tested.

Observations and Results

Key outcomes observed during testing:

- **Top Emission Contributors**

o Transportation and household energy usage emerged as the most significant contributors to individual carbon footprints.

o Users relying on private transport or extensive electricity usage showed consistently higher emission levels.

- **Impact of Visual Feedback**

o Users found **data-driven visualizations** (charts and progress indicators) more relatable than plain numerical values.

o This improved their understanding and prompted reflection on daily habits.

- **Effectiveness of Personalized Suggestions**

o Behavior-change recommendations— such as using public transport, minimizing peak-time power use, and reducing unnecessary purchases—led to noticeable footprint reduction among users who applied them

consistently.

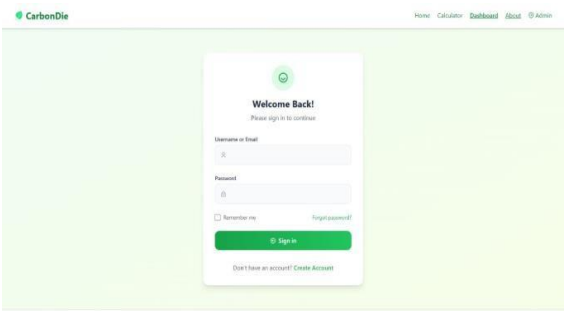

Fig.4 Login Page

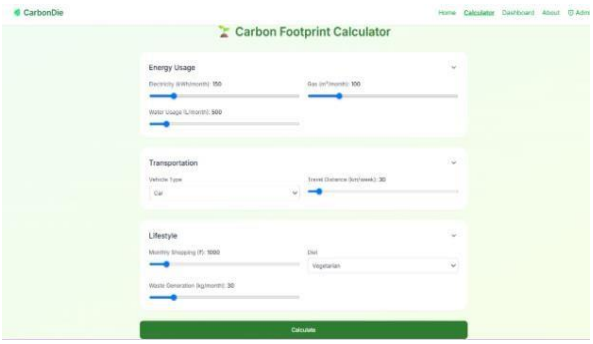

Fig.5 Calculator Module

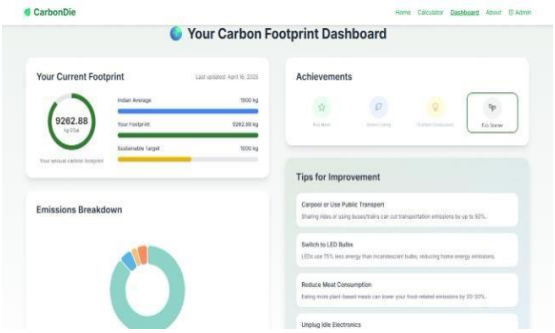

Fig.6 Calculator Dashboard Module

Advantage

a. **Real-Time Carbon Emission Monitoring :** This feature unifies all student data—such as contact information, academic records, and social media links—into a single, easily accessible system. By consolidating data in one place, it simplifies information retrieval for staff and faculty, reduces data redundancy, and enhancesthe overall eff iciency of managing student records. This centralization ensures that essential details are available whenever needed, improving organization and accessibility.

b. **Personalized, Data-Driven Recommendations:** Utilizes AI algorithms to analyze user behavior patterns and generate optimized, actionable strategies for emission reduction tailored to individual profiles.

c. **Modular and Scalable System Design:** The architecture supports flexible integration of additional functionalities, such as advanced analytics or voice-controlled interfaces, ensuring adaptability to evolving user needs and technological advancements.

d. **Advanced Visualization Techniques:** Employs dynamic visual representations, including interactive pie charts and augmented reality overlays, to convey complex carbon data intuitively, improving user comprehension and motivation.

e. **Comprehensive Data Collection and Storage:** Aggregates user inputs into structured databases and spreadsheet formats, creating a rich dataset that supports ongoing machine learning model refinement and improved predictive accuracy.

f. **Localized Contextualization for Indian Demographics:** Customizes emission factors and recommendations based on region-specific lifestyle attributes and cultural practices, increasing relevance and effectiveness for target users.

g. I**ntegration with Sustainable Local Ecosystems:** Connects users to regional green businesses and eco-conscious organizations via an interactive platform, fostering community engagement and facilitating sustainable economic growth.

h. **Alignment with User Demand for Sustainability Tools:** Addresses the rising market need for accessible, user-centric carbon management solutions, thereby increasing adoption rates among environmentally conscious demographics.

i. **Community-Driven Features:** Enables collaborative challenges, peer support networks, and knowledge sharing to build a cohesive user base invested in collective environmental impact.

Disadvantage

a. Data Accuracy & Input Reliability : The precision of carbon calculations heavily depends on user honesty and data granularity. Inaccurate or incomplete inputs lead to skewed results, undermining trust in the tool's recommendations.

b. Scalability in Diverse Demographics : Adapting the app for diverse user bases—especially in rural or low-tech areas—requires extensive localization of data sources and UI/UX. Without this, the app risks low adoption and relevance.

c. Computational & Resource Constraints

Real-time AI and AR features demand significant processing power and stable internet, which can limit usability on low-end devices and in bandwidth-restricted environments.

Conclusion

This carbon footprint calculator transcends traditional tracking tools by evolving into a comprehensive platform for actionable environmental transformation. Leveraging AI-powered prediction models, the system not only estimates emissions with precision but also anticipates user behavior to offer context-aware, low- impact alternatives tailored to individual lifestyles.

The proposed integration with fitness trackers introduces a novel intersection between personal wellness and sustainability—demonstrating how eco-conscious living can enhance health outcomes. Collaborations with green product vendors will operationalize sustainable choices, converting user awareness into immediate, measurable actions.

Further, by incorporating IoT-based real-time data collection, the app aims to eliminate manual input barriers, ensuring seamless and highly accurate emissions tracking. Gamified experiences and social engagement modules will shift environmental action from isolated efforts to community-driven momentum, using challenges, leaderboards, and rewards to sustain motivation.

Localization capabilities and multilingual support ensure adaptability across geographies and demographics, while scalability plans for institutional adoption—such as in schools, companies, and policy frameworks—position the platform as a tool for systemic environmental change.

In essence, this platform redefines the scope of a carbon calculator. It becomes a dynamic ecosystem for sustainable living—bridging personal behavior with collective impact and translating digital interaction into real-world carbon reduction. It empowers users to turn climate awareness into daily, data-backed decisions— contributing meaningfully to the Bharat Net-Zero Mission and global climate action goals.

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