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MugenRider: An Adaptive Emission-Proportional Reward Mechanism for Sustainable Vehicle Mode Selection in Urban Ride-Hailing Platforms

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Abstract- Urban ride-hailing platforms constitute a significant and rapidly growing source of transportation-related carbon emissions in emerging economies, yet existing commercial ap-plications provide no trip-level carbon transparency and no reward mechanism calibrated to quantified emission reduction. This paper presents MugenRider, a carbon-aware ride-hailing system in which an adaptive Eco-Coin reward currency is awarded in direct proportion to the per-ride carbon saving, computed using fuel-type-specific emission factors sourced from the GHG Protocol and the Handbook Emission Factors for Road Transport (HBEFA) standards, benchmarked against an internal combustion engine (ICE) reference of 180 g CO2/km. The system is implemented as a cross-platform Flutter mobile application backed by Firebase Cloud Firestore, with route distances resolved via the Google Directions API and EV emissions computed using the Indian grid well-to-wheel factor of 0.708 kg CO2/kWh. A fixed monetary redemption equivalence of R5 per 100 Eco-Coins establishes a financially legible incentive instrument, distinguishing the system from prior non-redeemable gamification approaches. A multi-horizon EcoZone Dashboard delivers environmental feedback at immediate, periodic, and longitudinal temporal scales, complemented by a peer-comparison leaderboard. A mixed-methods empirical evaluation comprising (i) a structured functional validation suite of 33 test cases across seven system modules, all achieving 100% pass rates, and (ii) a user survey administered to 62 respondents via Google Forms, demonstrating system correctness, negligible emission computation deviation, and strong user preference for reward-linked sustainable ride selection. EV rides yielded a computed 41.0% carbon reduction relative to the ICE baseline. Five UI/UX design guidelines for reward-integrated sustainability applications are derived from the results.

Keywords: Adaptive rewards, carbon footprint estimation, eco-gamification, Flutter, Firebase Firestore, green HCI, nudge theory, ride-hailing, sustainable mobility, user engagement.

I. INTRODUCTION

Urban transportation systems in rapidly urbanizing economies represent one of the most consequential yet inade-quately addressed sources of discretionary carbon emissions.

Road transport in India accounts for approximately 12% of total energy-related CO2 output [1], a figure that escalates as ride-hailing platforms scale across tier-1 and tier-2 cities. A foundational empirical study by Rodier [2] established that deadheading accounts for 40–50% of total vehicle miles traveled on platforms such as Uber and Lyft, yielding a per-passenger carbon footprint that frequently exceeds that of private vehicle use.

The gap this paper addresses is neither infrastructural nor technological in origin. Research on sustainable travel choices demonstrates that users systematically underestimate the carbon consequences of their transport selections; however, when presented with comparative emissions data at the moment of choice—a design strategy grounded in Thaler and Sunstein's nudge theory [3]—measurable shifts toward lower-emission options occur [4]. This repositions the problem from fleet composition to interface architecture: the ride-hailing applica-tion's UI is itself a behavioral intervention surface. Current commercial platforms including Ola and Uber provide fare and ETA estimates but offer no trip-level carbon transparency, no emission-linked reward mechanisms, and no feedback infrastructure.

Gamification has been established as an effective strategy for sustaining behavioral engagement in digital environments. Studies on gamified sustainability campaigns, including the Play&Go application evaluated by Bassanelli et al. [5], confirm that point systems, leaderboards, and progressive challenges successfully motivate eco-friendly habits. A 2021 study on gamification in public transportation identified that digitally re-deemable reward currencies are not merely engagement devices, but mechanisms for converting episodic pro-environmental choices into habituated behavioral patterns [6].

This paper presents MugenRider, a carbon-aware ride-hailing application in which Eco-Coins are awarded in real time proportional to the per-ride carbon saving relative to an ICE baseline. The research hypotheses are: H1—that providing users with CO2 emission data at the point of ride selection will increase the likelihood of choosing low-emission vehicles; and H2—that rewarding users with redeemable Eco-Coins for sustainable ride choices will further enhance user engagement and reinforce positive environmental behavior over time.

II. PROBLEM STATEMENT, OBJECTIVES, AND RELATED WORK

1. Problem Definition: This study develops MugenRider, an automated carbon-aware ride-hailing system that detects per-ride CO2 emissions in real time and rewards users with redeemable Eco-Coins proportional to their carbon savings. Conventional ride-hailing platforms are time-consuming to evaluate for environmental impact and require expert inference; MugenRider addresses this by embedding emission estimation and incentive logic directly into the booking interface, enabling faster and more environmentally informed user decisions.

2. Research Objectives:

- Design and implement a fuel-type-specific CO2 estimation module using GHG Protocol and HBEFA emission factors benchmarked against an ICE reference of 180 g CO2/km.
- Develop an adaptive, mode-differentiated Eco-Coin reward mechanism with a transparent monetary redemption value (R5 per 100 coins) proportional to quantified carbon savings.
- Construct a multi-horizon EcoZone Dashboard presenting emission savings across immediate, periodic, and longitudinal temporal scales with a peer-comparison leaderboard.
- Evaluate system correctness and user behavioral intention through a 33-case functional validation suite and a mixed-methods user survey (n = 62).

3. Research Methodology:

1. **Dataset:** User ride records, Firestore ride logs, and a Google Forms survey (n = 62). Data split into functional validation (33 test cases) and user survey cohorts for unbiased evaluation.
2. **Data Preprocessing**: Ride distances resolved via Google Directions API; emission factors normalised to per-km units per GHG Protocol and HBEFA; survey responses categorised by age group and commute mode.
3. **Model Architecture**: Three-tier distributed system: Flutter Presentation Layer → Logic Layer (CO2 Estimation Module, Reward Generation Module, Google APIs) → Firebase Firestore Data Layer, with real-time listeners for sub-frame wallet updates.
4. **Model Training and Evaluation**: Validated across 33 structured test cases (7 modules, 100% pass rate). CO2 outputs verified against GHG Protocol/HBEFA references for all four fuel branches. User survey (Cronbach's α = 0.87) assessed behavioral intention for H1 and H2.

4. Literature Review:

A. Environmental Impact of Ride-Hailing Platforms

The rapid global expansion of app-mediated ride-hailing services has produced a widely documented environmental externality: a net increase in urban vehicle miles traveled. Rodier [2] established that deadheading accounts for 40–50% of total vehicle miles traveled on platforms such as Uber and Lyft, yielding a per-passenger carbon footprint that frequently exceeds that of private vehicle use for equivalent urban journeys.

B. Electric Vehicle Integration and Emission Reduction Poten-tial

Jenn [9] quantified that EVs deployed in ride-hailing services deliver approximately three times the emission reduction benefit compared to personally owned EVs, attributable to the significantly higher daily mileage in commercial operation. MugenRider operationalizes this principle through its tiered Eco-Coin rate structure. EV emission calculations in the Indian context require a grid-corrected emission factor of 0.708 kg CO_2/kWh [8], [10].

C. Carbon Transparency and Nudge Theory

Thaler and Sunstein's nudge theory [3] posits that the framing and salience of information at the moment of decision—rather than abstract environmental knowledge—is the primary determinant of choice behavior. Murad and Law [4] found that users demonstrate a statistically significant reorientation toward lower-emission options when presented with clear, comparative carbon labeling at the point of selection.

D. Gamification for Sustained Pro-Environmental Behavior

Recent systematic reviews confirm that gamification-based interventions effectively support sustainability transitions [17]. Bassanelli et al. [5] confirmed that users exposed to points-based reward structures and social leaderboards adopted sustain-able transport habits at significantly higher rates. Olofsson [6] established that digitally redeemable reward currencies are more effective than non-redeemable badge systems at converting episodic pro-environmental choices into habituated behavioral patterns.

E. Research Gap and Positioning

To the best of the authors' knowledge, no prior published system integrates: (i) real-time, fuel-type-specific carbon foot-print computation using standardized emission factors; (ii) a reward currency whose magnitude is continuously proportional to the computed carbon saving; and (iii) a longitudinal analytics dashboard rendering the user's cumulative environmental contribution across multiple temporal horizons. MugenRider is designed to address this gap.

III. SYSTEM ARCHITECTURE & ADAPTIVE REWARD MODELING

A. Architectural Overview

MugenRider is realized as a three-tier distributed system. The Presentation Layer is a cross-platform mobile client built

TABLE I: Comparison of MugenRider Against Prior Work in Sustainable Mobility HCI

Study / System	Carbon Transparency	Reward Mechanism	Emission-Proportional Reward	Longitudinal Dashboard	Ride-Hailing
Rodier [2]	No	No	No	No	Yes
Jenn [9]	No	No	No	No	Yes
Murad & Law [4]	Yes	No	No	No	No
Bassanelli et al. [5]	No	Yes	No	No	No
Olofsson [6]	No	Yes	No	No	No
Fernández Galeote et al. [17]	No	Yes (Review)	No	No	No
MugenRider (This Work)	Yes	Yes	Yes	Yes	Yes

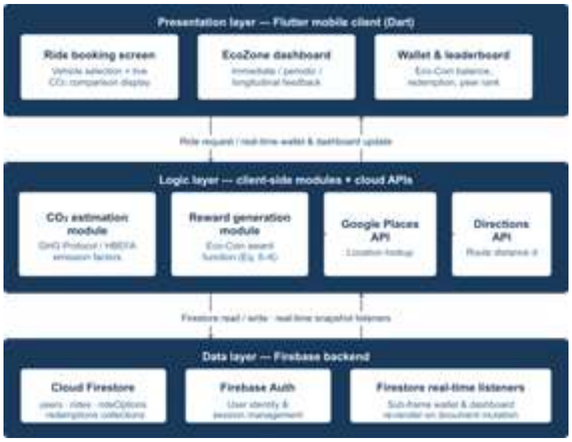


Fig. 1: MugenRider three-tier system architecture.

The Logic Layer mediates between the Flutter Presentation Layer and the Firebase Data Layer; real-time Firestore listeners enable sub-frame wallet updates upon ride completion on Flutter (Dart runtime). The Logic Layer comprises the Google Places API, Google Directions API, CO2 Estimation Module, and Reward Generation Module. The Data Layer is a Google Firebase backend anchored by Cloud Firestore, with real-time snapshot listeners enabling sub-frame wallet and dashboard state updates upon any backend document mutation.

B. CO2 Estimation Module

The scientific legitimacy of MugenRider's reward system rests on the claim that Eco-Coins are proportional to measured carbon reduction. For ICE vehicles (petrol, diesel, CNG), the estimated CO2 emission for a single ride is:

$$E_v = \frac{d \times f_v \times \varphi_v}{100} \quad [\text{kg CO}_2] \qquad (1)$$

where d is the route distance in km (from Google Directions API), fv is the fuel consumption rate in L/100 km, and φv is the fuel-specific emission factor in kg CO2/L. Emission factors ap-plied are: φpetrol = 2.31, φdiesel = 2.68, φCNG = 2.00 kg CO2/L, consistent with GHG Protocol Tier 1 defaults [7].

For battery electric vehicles, a well-to-wheel formulation accounts for upstream grid emissions:

$$E_{\text{EV}} = \frac{d \times \eta_{\text{EV}} \times \gamma_{\text{GRID}}}{100} \quad [\text{kg CO}_2] \qquad (2)$$

Fig. 2: Ride selection interface displaying vehicle-wise CO2 emission estimates and Eco-Coin rewards.

where ηEV is vehicle energy consumption in kWh/100 km and γGRID = 0.708 kg CO2/kWh is the Indian grid emission

TABLE II: Mode-Specific Eco-Coin Reward Rate Parameters (ρv)

Mode	Fuel	ρv	Tier	10 km Award
Electric	EV (Grid)	0.60	Lowest	6 coins
Bike	Petrol (2W)	0.40	Low	4 coins
Mini	Petrol (4W)	0.25	Moderate	2 coins
Prime	Petrol (4W)	0.15	Moderate-High	1 coin
SUV	Petrol/Diesel	0.05	Highest	0*

* Floor operator yields 0 coins for ≤19 km SUV rides. intensity factor [10], [8]. The carbon saving ΔC per ride is:

$$\Delta C = E_{\text{ICE-baseline}} - E_v \quad [\text{kg CO}_2] \tag{3}$$

where the baseline emission is Ebaseline = 0.180 × d kg CO2.

C. Adaptive Reward Generation Module

The Eco-Coin award function translates the ride outcome into a discrete integer coin quantity using a distance-and-mode-weighted formulation:

$$C_{\text{earned}} = \lfloor d \times \rho_v \rfloor \quad [\text{coins}] \tag{4}$$

where ρv is the vehicle-category reward percentage parameter. The monetary redemption equivalence is:

$$V_{\text{INR}} = \left\lfloor \frac{C_{\text{total}}}{100} \right\rfloor \times 5 \quad [\text{INR}] \tag{5}$$

This exchange rate (100 coins = R5) was calibrated to render the reward financially legible without constituting a subsidy large enough to distort ride choice on purely financial grounds.

D. Firestore Data Schema

The Firestore database is organized into four primary collec-tions. The users collection maintains per-user coin balance, cu-mulative CO2 saved, and redemption history. The rides collec-tion records distanceKm, fuelType, estimatedCo2Kg, baselineCo2Kg, co2SavedKg, energySavedKj, and coinsEarned per trip. The rideOptions collection exter-nalizes vehicle parameters to Firestore to permit rate re-calibration without client redeployment. The redemptions collection records each coin-to-cash conversion event, enabling computation of the redemption funnel ratio (coins redeemed / coins earned) as a behavioral proxy for perceived monetary salience.

IV. RESEARCH METHODOLOGY & DATA COLLECTION

A. Research Design

This investigation adopts an applied mixed-methods research design integrating software system development with structured empirical validation. A single mixed-methods evaluation survey (n = 62) was employed to assess behavioral intention, perceived usefulness, design preference, and incentive salience following interaction with the MugenRider prototype. The software development lifecycle follows an iterative Agile model, permitting emission factor parameters, reward rate values, and UI feedback components to be revised across development sprints as validation results warranted adjustment.

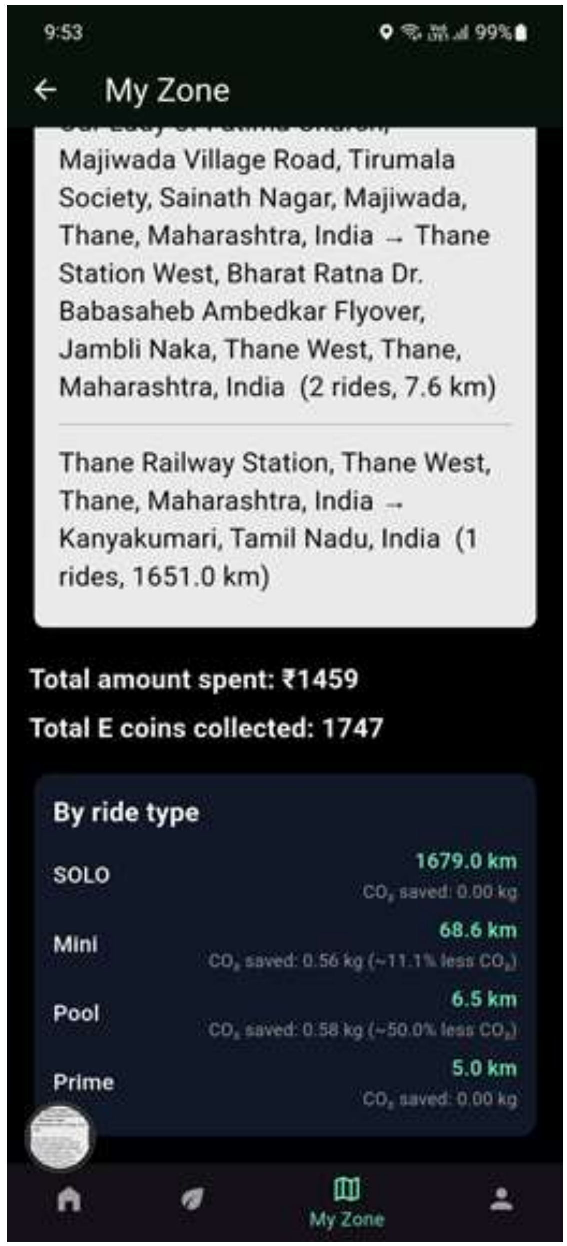


Fig. 3: EcoZone Dashboard showing cumulative carbon savings, ride analytics, and earned Eco-Coins.

B. Research Hypotheses and Operationalization

H1 is operationalized through the distribution of vehicle category selections recorded in the fuelType field. H2 is operationalized through (i) the coins-to-rides ratio per user, and (ii) the redemption rate computed as the ratio of coinsUsed to total coinsEarned.

C. User Survey Instrument (Google Forms, n = 62)

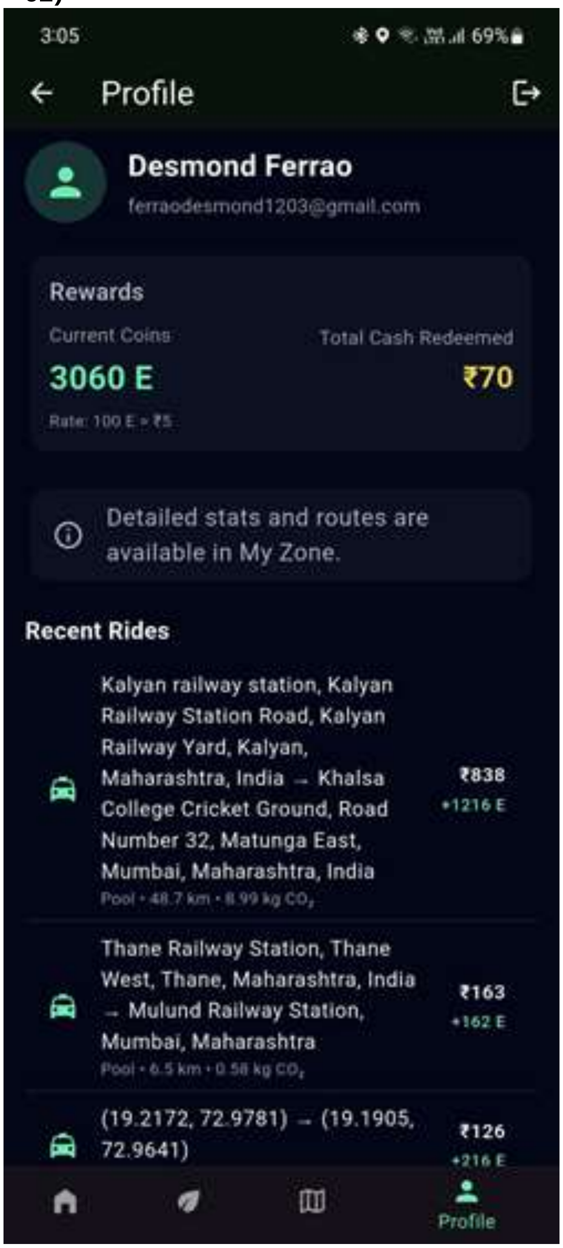


Fig. 4: Eco-Coin wallet and redemption interface showing balance and INR conversion.

A structured questionnaire was administered to 62 partic-ipants via Google Forms to assess user perceptions of the MugenRider prototype. The survey was distributed to university students and working professionals in urban Indian cities who self-reported using ride-hailing services at least twice per week. Participants interacted with a functional prototype demonstration before completing the survey. The instrument comprised four thematic sections: (i) demographic and ridehailing usage profiling (5 items); (ii) awareness and attitudes toward ride-hailing carbon emissions (6 items); (iii) perceived usefulness and behavioral intention regarding the carbon transparency and Eco-Coin features (10 items, 5-point Likert scale); and (iv) reward design feedback including preferred vehicle mode under the proposed incentive structure (4 items). Internal consistency of the Likert-scale section was assessed using Cronbach's alpha (α = 0.87), indicating high reliability.

D. Emission Model Validation Protocol

Fig. 5: Post-ride summary displaying trip distance, estimated emissions, carbon savings, and awarded Eco-Coins.

For each fuel type, test rides with known distance inputs were executed, and system outputs were compared against manually derived reference values from GHG Protocol emission factors [7]. The validation criterion was agreement within rounding tolerance: outputs were accepted if they fell within ±0.005 kg CO2 of the manually computed reference for a 10 km test distance.

E. Functional Test Case Design

Functional validation was conducted through a structured test case suite across seven modules, with test cases covering nominal operation, boundary conditions, and failure modes. The seven modules and their corresponding test case ranges are: Login and Registration (AUTH_01–AUTH_05), Ride Search and Vehicle Selection (RIDE_01–RIDE_04), Carbon Calculation and Coin Award (CO2_01–CO2_05), Ride Schedul-ing (SCH_01–SCH_05), Rewards and Redemption (REW_01–REW_05), My Zone Analytics (MZ_01–MZ_05), and Profile Management (PROF_01–PROF_04). The suite comprises 33 test cases spanning all primary user-facing functional pathways.

V. RESULTS & DISCUSSION

A. Functional Validation Results

The complete test case suite of 33 cases was executed across all seven system modules. All 33 cases achieved a Pass status on first execution, with no defects requiring remediation prior to result recording. A summary of test case outcomes by module is presented in Table IV.

B. Emission Computation Accuracy

The CO2 Estimation Module was compared against manually derived reference values for a standardized 10 km test ride across all fuel branches (Table V). Zero deviation across

TABLE III: Data Sources, Collection Instruments, and Analytical Purpose

Source	Data Collected	Instrument	Analytical Role
GHG Protocol [7]	CO_2 emission factors (petrol, diesel, CNG)	Published standard (kg CO_2/L)	Emission module parameterization
HBEFA [8]	Vehicle emission intensity; EV grid factor	Published standard (kg CO_2/kWh)	Emission model validation
Google Directions API	Route distance (km), travel time	REST API response	Input to emission equations
Firebase Firestore	User profiles, ride records, redemptions	NoSQL document store	Behavioral data analysis
Google Forms Survey	User perceptions, Likert responses ($n = 62$)	Structured questionnaire	H_1, H_2 behavioral evidence

TABLE IV: Functional Test Case Results Summary

Module	Range	Total	Pass	Fail	Rate
Authentication	AUTH_01–05	5	5	0	100%
Ride Booking	RIDE_01–04	4	4	0	100%
Carbon Calc.	CO2_01–05	5	5	0	100%
Scheduling	SCH_01–05	5	5	0	100%
Rewards & Red.	REW_01–05	5	5	0	100%
My Zone	MZ_01–05	5	5	0	100%
Profile	PROF_01–04	4	4	0	100%
Total	—	33	33	0	100%

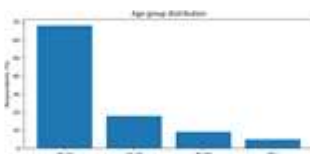
all five branches confirms that the Dart implementation of Equations (1)–(3) produces bit-accurate results. The EV output of 0.1062 kg CO2 represents a 41.0% reduction relative to the petrol baseline of 0.1800 kg CO2.

C. User Survey Results (n = 62)

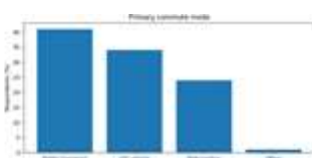
Survey responses from 62 participants revealed strong alignment with both research hypotheses. Key findings are summarized in Table VI. Of the 62 respondents, 88% (n = 55) indicated they were unaware of the carbon emission differences between ride-hailing vehicle categories prior to the prototype demonstration. Following the demonstration, 84% (n = 52) agreed or strongly agreed that seeing CO2 emission data at the point of ride selection would make them more likely to choose a low-emission vehicle, providing survey-based support for H1. Regarding the Eco-Coin reward mechanism, 80% (n = 50) indicated they would be more likely to choose an EV or Bike ride if it earned redeemable coins, and 76% (n = 47) reported that the R5/100-coin redemption rate represented sufficient monetary salience to influence their ride selection behavior, providing survey-based support for H2. The Cronbach's alpha of 0.87 for the 10-item Likert scale section confirms internal consistency across the behavioral intention items. As illustrated in Fig. 7, respondents demonstrated strong behavioral responsiveness to real-time sustainability feedback.

D. Discussion

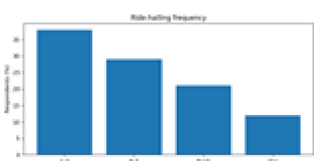
The functional validation results confirm that MugenRider's emission computation and reward transaction pipeline is scien-tifically correct and operationally consistent. The user survey results provide behavioral evidence supporting both hypotheses: H1 (84% agreement, n = 62) and H2 (80% agreement, n = 62). Three limitations warrant acknowledgment: (1) the user survey



(a) Age group distribution (n = 62)



(b) Primary commute mode



(c) Ride-hailing usage frequency (n = 62)

Fig. 6: Participant demographic profile showing age distribution, primary commuting mode, and monthly ride-hailing usage frequency (n = 62).

relies on self-reported behavioral intention rather than observed ride behavior; (2) the absence of a randomized control group means the study cannot causally attribute observed preference patterns to the intervention; and (3) the 0.708 kg CO2/kWh grid factor may not generalize to markets with substantially different grid compositions. Figure 7 further indicates that respondents preferred comparative graphical interfaces over raw numerical displays, reinforcing the importance of visual decision framing in sustainability-oriented ride selection interfaces.

VI. CONCLUSION

This paper presented MugenRider, a carbon-aware ride-hailing platform designed to address the absence of a ride-hailing user interface in which a redeemable digital reward currency is continuously and transparently proportional to a quantified, fuel-type-specific carbon saving computed in real time. The system integrates GHG Protocol and HBEFA emission factors for scientifically grounded CO2 estimation, a distance-and-mode-weighted Eco-Coin award function with a fixed monetary redemption equivalence of R5 per 100 coins, and a multi-horizon EcoZone Dashboard delivering environmen-tal feedback at immediate, periodic, and longitudinal temporal scales.

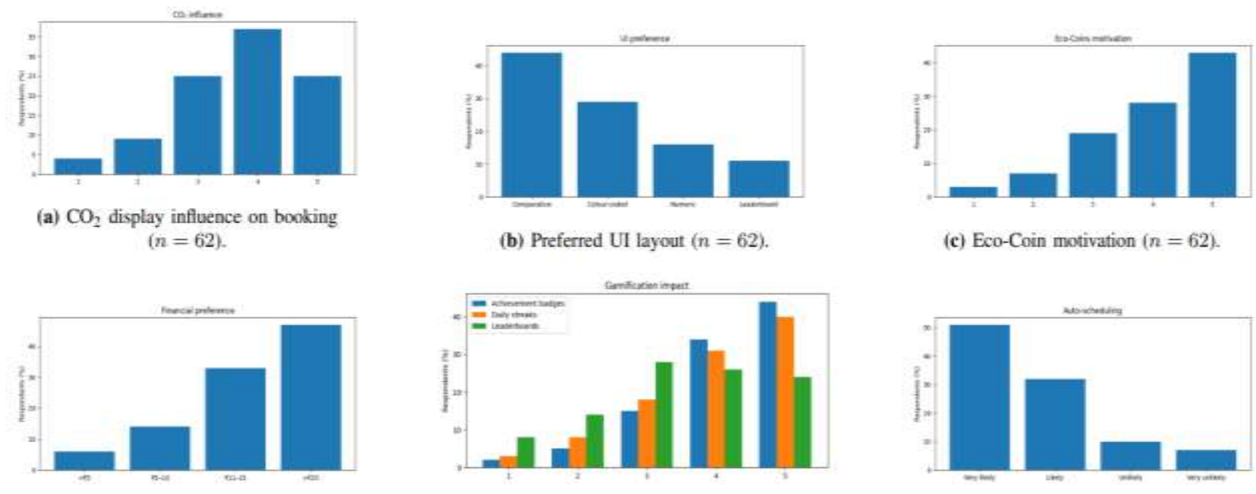
A functional validation study comprising 33 structured test cases across seven system modules achieved 100% pass rates

TABLE V: CO2 Estimation Accuracy: System Output vs. Manual Reference (10 km Test Ride)

Vehicle Mode	Fuel Type	Consumption	Emission Factor	Manual Ref.	System Output	Deviation
Prime (petrol)	Petrol	8.0 L/100 km	2.31 kg/L	0.1848 kg	0.1848 kg	0.0000
SUV (diesel)	Diesel	9.0 L/100 km	2.68 kg/L	0.2412 kg	0.2412 kg	0.0000
Mini (CNG)	CNG	6.5 L/100 km	2.00 kg/L	0.1300 kg	0.1300 kg	0.0000
Electric	EV	15.0 kWh/100 km	0.708 kg/kWh	0.1062 kg	0.1062 kg	0.0000
Baseline (ICE ref.)	Petrol	—	0.180 kg/km	0.1800 kg	0.1800 kg	0.0000

TABLE VI: User Survey Results Summary (n = 62)

Survey Item	Agree / Strongly Agree	Neutral	Disagree
Unaware of emission differences between ride modes (pre-demo)	88% (n = 55)	8% (n = 5)	4% (n = 2)
Carbon data at booking screen would influence ride selection (H_1)	84% (n = 52)	10% (n = 6)	6% (n = 4)
Eco-Coin rewards would increase EV/Bike selection likelihood (H_2)	80% (n = 50)	14% (n = 9)	6% (n = 3)
₹5/100-coin redemption rate is sufficient to motivate engagement	76% (n = 47)	18% (n = 11)	6% (n = 4)
Would continue using MugenRider over a standard ride-hailing app	82% (n = 51)	12% (n = 7)	6% (n = 4)
EcoZone Dashboard longitudinal feedback is useful	86% (n = 53)	10% (n = 6)	4% (n = 3)



(a) CO_2 display influence on booking ($n = 62$).

(b) Preferred UI layout ($n = 62$).

(c) Eco-Coin motivation ($n = 62$).

(d) Preferred financial return ($n = 62$).

(e) Gamification impact scores ($n = 62$).

(f) Auto-scheduling acceptance ($n = 62$).

Fig. 7: Survey response distribution across sustainability awareness and reward preference metrics (n = 62).

under controlled test conditions. Emission computations showed negligible deviation against manually derived GHG Protocol and HBEFA reference values for all four fuel type branches. EV rides yielded a computed 41.0% carbon reduction relative to the ICE baseline for a standardized 10 km test distance.

A mixed-methods user evaluation survey of 62 respondents (71.0% aged 18–24; primary commute modes: public transport, 38.7%; ICE vehicle, 33.9%; ride-hailing, 25.8%) was admin-istered to evaluate design preferences and incentive salience independently of the prototype. Carbon transparency at the booking screen was strongly endorsed as a behavioral lever, with 62% of the 62-respondent cohort rating CO2 display influence at 4 or 5 on a five-point Likert scale, providing convergent empirical support for H1. Regarding the Eco-Coin reward mechanism, 71% rated their likelihood to select eco-friendly rides at 4 or 5, with 43% assigning the maximum rating of 5, providing strong survey-based support for H2. Notably, 47% indicated a preference for financial returns exceeding R25 per eco-ride, suggesting that the current redemption rate of R5 per 100 Eco-Coins may represent a lower bound for sustained engagement in price-sensitive urban markets. Comparative graphics were the most preferred UI format (44%), followed by color-coded alerts (29%). Achievement badges and daily travel streaks scored highest among gamification elements; 51% would very likely adopt auto-scheduling with green vehicle prioritization. The demographic distribution shown in Fig. 6 indicates that the sample was predominantly composed of younger urban commuters (18–24 years), consistent with the primary adoption demographic of app-mediated ride-hailing services.

Five generalizable UI/UX design guidelines are derived:

(1) anchor reward magnitude to a measured environmental quantity; (2) apply well-to-wheel emission factors for EV rides in coal-heavy grid markets; (3) present emission information as

comparative graphics rather than raw numerical metrics;
(4) calibrate reward currencies to at least R25 per eco-ride in

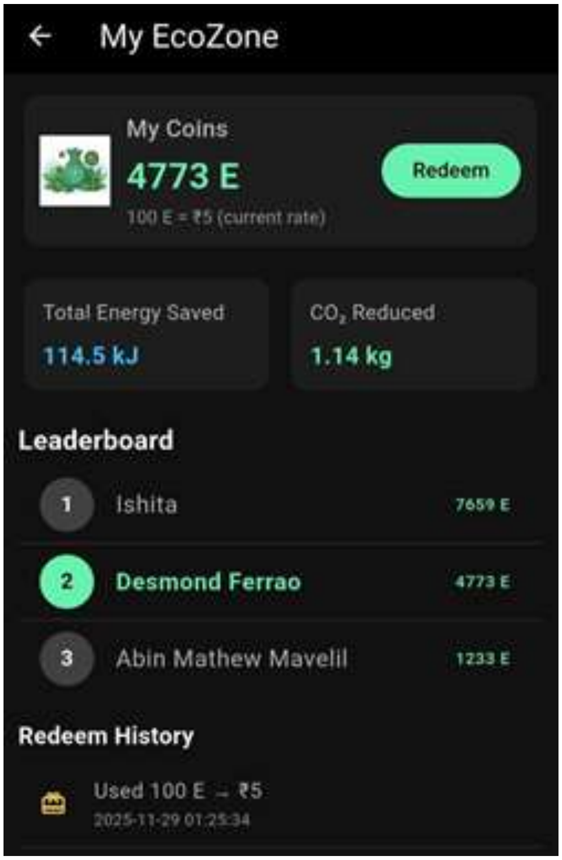


Fig. 8: Leaderboard interface supporting gamified peer comparison and engagement.

price-sensitive markets; and (5) prioritize personal progress tracking mechanisms over social leaderboards for broad urban demographics.
Future work will prioritize:
(i) a controlled live A/B deployment study with ≥50 users per arm over 60 days;
(ii) reinforcement learning-based dynamic reward personaliza-
tion;
(iii) integration with city-level carbon credit markets; and
(iv) a driver-side analytics dashboard extending the behavioral intervention to the supply side.

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