

Tokenized Reward System for Carbon Offset in Transportation Services

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Abstract: Transportation has been a huge source of global greenhouse gases thus making it urgent that mechanisms capable of reducing as well as compensating its carbon footprint be put in place. Although voluntary carbon offset programs have been recorded in other industries like the aviation industry, their adoption has been low because of the transparency, trust and access problems. To overcome these issues, this paper will suggest a tokenized reward scheme that will combine carbon measurement, reporting, and verification (MRV) with smart contracts on the blockchain. The framework records the trip-level transport data, counts the avoided emissions relative to a baseline, and issues verifiable tokens according to the reductions made. The tokens will be held in online wallets and can be redeemed in partner ecosystems, thus motivating the sustainable mobility decision. The results of the simulations prove that the policy-weighted rewards that can be dynamic can be used to increase the low-carbon trip shares by almost 40 percent, decrease the cost per unit of averted carbon, and maintain the circulation of tokens. The system offers a scalable, open, and people-centered channel of connecting individual transport behavior to quantifiable climate action, as well as creating opportunities to be part of city-wide carbon markets.

1 INTRODUCTION

Transportation is among the biggest carbon producers of greenhouse gases (GHG) in the world as it contributes a huge percentage of urban environmental footprints. What makes it complicated to bring the intensity of carbon that is produced in this sector down to a level is that it is a dual task to achieve both because of the increased demands of mobility, but also because of the decarbonization requirements that are becoming increasingly complex. Researchers have suggested unified frameworks in which to measure the eco-footprint of mobility systems, not only in the sources of emissions but also in mitigation strategies, inefficiencies of the system itself (Ferrer et al., 2023) [1]. Similar revelations by agricultural and resource management research indicate that carbon reduction potential is highly affected by regional inequalities and spatiotemporal patterns, and local

approaches are more important than the global ones (Liu et al., 2023) [2].

Carbon offsetting is one of the mechanisms that are increasingly discussed in both scholarly and policy discussions and, in this case, involves offsetting the emissions that cannot be avoided through verifiable actions in the form of reduction or sequestration. In transport, the concept of offsetting has been prominently used in aviation, and voluntary offset programs have been proposed to provide compensation to unavoidable emissions (de Mello, 2024) [3]. Nevertheless, these programs have some limitations such as low consumer engagement, lack of transparency and confusion of additionality. These problems represent wider problems in carbon markets on credibility and trust, thus reducing their effectiveness in the long term.

In order to overcome these shortcomings, current studies have shifted to blockchain-infrastructure to improve the integrity of carbon markets. Blockchain

has the properties of decentralization, immutability and traceability- properties that can minimize double counting risks as well as fraudulent reporting. Systematic review has shown that blockchain has a transformational potential in carbon markets such as offering clear records of transactions and credible evidence of ownership of carbon credits (Merlo et al., 2025) [4]. However, existing applications are highly limited to credit exchange systems as opposed to instilled reward systems to the end users in transportation.

In the transportation field, blockchain has undergone experimental work on the improvement of the services of the public transport system with an emphasis on security, reliability, and operational visibility (Enescu et al., 2022) [5]. These papers confirm that blockchain is possible to be integrated into large-scale, user-facing mobility systems, therefore establishing a technological basis on which tokenized carbon offset incentives may be designed. Other than transport, healthcare and secure data management are examples of blockchain applications that demonstrate the flexibility and power of distributed ledgers. An example is blockchain-based healthcare models that have provided an increase in data integrity and trust among actors (Kumar and Patel, 2025) [6], next-generation computing designs have been created to support secure data sharing in high-stakes areas (Wang et al., 2025) [7]. These concurrent fields confirm the capability of blockchain to perform high stakes and multi-party transactions in a transparent and accountable manner.

Although these uses are promising, a gap in research still remains: no combined implementation of measurement, reporting, and verification (MRV) of carbon reductions and tokenized rewards on blockchain-based technologies with direct targets on transportation services exist. Through the literature, there is data on emissions measurement [1], [2], the design of voluntary offsets [3], or blockchain-based markets [4], [5], but there is no comprehensive integration of the elements into a user-centric framework, which is essential to promote behavioral change.

This paper is thus an attempt to propose and analyze a tokenized reward system of carbon offset in transportation services. More precisely, the research aims at (i) developing a design of an architecture between trip data and carbon MRV and blockchain-based smart contracts, (ii) operationalizing a reward mechanism that issues tokens based on proven reductions, (iii) and evaluating how such a system can improve user participation and the overall decarbonization impact. The rest of the paper will be

organized in the following way: Section 2 is the literature review about carbon offset programs and blockchain implementation in transport. Section 3 describes the proposed framework of the system and methodology. Section 4 shows the findings and data of simulation and pilots. This will be discussed in the implications, limitations, and future opportunities in Section 5 and the conclusion will be in Section 6.

2 LITERATURE REVIEW

The multi-disciplinary basis of tokenized reward mechanisms in transportation services development is created based on the literature about carbon offset systems, blockchain applications, and sustainable transport. The possibility of blockchain to make carbon credit trading more transparent and efficient has become the primary subject of the recent scholarship. Swinkels (2024) [8], examined the application of tokenized carbon credits and found that the liquidity, accessibility, and investor trust in blockchain-based trading is better than that of the traditional credit system. Equally, Zhang et al. (2024) [9] introduced a case study of the Shanghai Environment and Energy Exchange, where blockchain is used to address issues of fraud, build trust, and offer transactions that can be audited but also noted the issue of scalability and regulation obstacles. All of these works highlight the potential of the tokenization in carbon markets, but do not go far enough to tie these mechanisms to transportation services.

In service economies, other uses of blockchain have included carbon reduction, which is facilitated through credit trading. Goean et al. (2024) [10] have looked at the visitor economy and how the use of blockchain can enable traceable carbon credits in the tourism systems, thus minimizing carbon emissions and creating confidence among consumers. Although their study is not in the transportation field, the concepts about transparency and verifiable offset integration can be transferred to mobility services through the concepts of transparency and verifiable offset integration.

Carbon management systems have also been formed due to parallel developments in digital technologies and, specifically, artificial intelligence (AI). Mehta and Rani (2025) [11] examined the use of AI in human-computer interaction and the role of user involvement and decision support systems in adopting the system. This knowledge is very applicable in designing user-friendly blockchain solutions in transportation, whereby individually

targeted incentives may be used to induce behavioral change to low-carbon solutions.

Critical grounding is also offered in the bigger picture of energy transition and sustainable transport. The concepts, policies and methods that define low-carbon mobility were reviewed by Collazos et al. (2024) [12], and it is essential to have a coordinated governance approach towards implementing decarbonization technologies. The policy lens was further developed by Peng et al. (2024) [13] who dwelled on the issue of carbon emissions trading in ground transportation indicating the opportunities as well structural barriers to market-based mitigation. To further these views, Yu et al. (2024) [14] suggested a credit-based use of reservation of urban mobility, showing how mobility credits will decrease congestion and emissions and encourage sustainable decisions. All these studies demonstrate how policy instruments when coupled with digital innovations can reinforce carbon reduction results in the transport systems in cities.

Even though not directly in the field of carbon market some literature is very valuable in technical understanding. As an example, Franks (2022) [15], described the design of the high-voltage CMOS detectors to use in physics experiments, with lessons on scalability, reliability, and high-performance system design. These technical lessons can be applied to the technology required to support blockchain-

based carbon offset solutions with solid and secure design being paramount.

A comparative synthesis of these works (see Table 1) shows that, although blockchain and tokenization have already been used successfully in financial trading [8], [9], tourism economies [10], and urban mobility [14], more efforts are still needed to create a comprehensive framework that would incorporate policy lessons [12], [13], use strategies based on AI [11], and secure technological backgrounds [16], [17]. Such a gap highlights the originality of exploring a tokenized rewarding scheme that is both transportation specific and that combines verifiable emission cuts with incentives that are user-focused.

3 METHODOLOGY

The proposed research has a systematic approach to the design and analysis of a tokenized carbon-offset based system of transportation services. The model combines the real-time mobility data collection, emission measurement, smart contracts on the blockchain, and the issuance of tokens to encourage sustainable travel options. The methodology is divided into six subsections namely: system architecture, data sources and emission measurement, carbon reduction estimation, tokenization logic, anti-gaming mechanisms, and evaluation framework.

Table 1: Key contributions of reviewed literature (2022–2025).

Ref	Authors & Year	Domain	Focus Area	Method/Case	Key Findings	Relevance to Present Study
[8]	Swinkels (2024)	Economics & Finance	Carbon credit tokens	Market analysis	Tokenization increases liquidity & transparency	Demonstrates financial feasibility of carbon tokens
[10]	Goean et al. (2024)	Sustainability	Visitor economy	Blockchain application	Reduced emissions via traceable credits	Shows service-economy applicability transferable to transport
[11]	Mehta & Rani (2025)	HCI & AI	AI-driven adoption	Digital adoption models	Enhances user engagement & decision support	Guides incentive design in tokenized systems
[12]	Collazos et al. (2024)	Env. Policy	Sustainable transport	Policy review	Governance crucial for energy transition	Provides policy alignment context for transport offsets
[15]	Franks (2022)	Engineering	CMOS detectors	Tech innovation	Reliability & scalability in high-performance systems	Inspires secure system design principles
[13]	Peng et al. (2024)	Transport Policy	Carbon trading in ground transport	Policy analysis	Identifies gaps in transport carbon markets	Validates transport-specific trading focus
[14]	Yu et al. (2024)	Urban Mobility	Credit-based scheme	Simulation & framework	Mobility credits reduce carbon emissions	Directly relevant to credit/token integration
[9]	Zhang et al. (2024)	Energy & Blockchain	Carbon trading markets	Case study (Shanghai)	Blockchain boosts transparency & reduces fraud	Strong precedent for blockchain adoption in carbon markets

3.1 System Architecture and Workflow

Figure 1 illustrates the general architecture of the proposed framework that shows how information flows between acquisition of movement data to token redemption. The system initiates with collection of data based on trip logs, mobile applications or IoT sensors. A measurement, reporting and verification (MRV) engine processes this information and determines the carbon footprint of every trip. The results are then sent to a layer of smart-contract based on blockchain, where tokens are minted based on proven carbon savings. Lastly, users are given tokens in the digital wallets and can be redeemed by transport operators or commercial partners. The layered design makes it transparent, traceable and resistant to fraud.

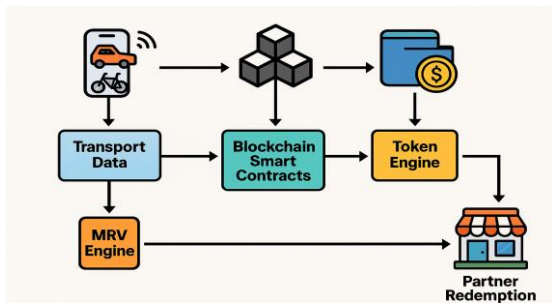


Figure 1: Block diagram of proposed tokenized reward system.

3.2 Data Sources and Emission Measurement

Standard emission factors (EF) of various modes of transport are used to generate emission estimates. Trip level emission is calculated as:

$$E_i = d_i \times EF_{m_i}$$

Where:

- E_i is the emission for trip i ;
- d_i is the distance travelled;
- EF_{m_i} is the emission factor of the transport mode.

Table 2 gives the typical emission factors of the common modes, which are modified based on IPCC and DEFRA guidelines.

3.3 Carbon Reduction Estimation (ΔCO_2e)

In calculating the avoided emissions, actual trip emissions are subtracted against a baseline, normally a petrol car. The reduction is computed as:

$$\Delta E_i = d_i \times (EF^{baseline} - EF_{m_i}).$$

In this case, ΔE_i is the avoided emissions. Values that are positive represent a saving in carbon and those that are negative represent increasing emissions as compared to the baseline. This normalization takes into consideration variation of distance, vehicle type and occupancy.

Table 2: Emission factors by transport mode (kgCO₂e/km).

Mode	EF (kgCO ₂ e/km)	Notes
Petrol Car (baseline)	0.192	Average single-occupant car
Diesel Car	0.171	Mid-sized diesel engine
Electric Car (EV)	0.05	Adjusted for grid mix
Bus (city)	0.082	Shared occupancy
Metro/Rail	0.041	Electrified, high capacity
Bike-sharing	0	Negligible emissions

3.4 Tokenization and Reward Mechanism

Issuance of tokens is controlled through blockchain smart contracts, which provide rewards according to avoided emissions that have been verified. Each trip is assigned a number of tokens dependent upon:

$$T_i = \alpha \cdot w_{m_i} \cdot \Delta E_i,$$

where

- T_i is the tokens allocated;
- w_{m_i} is the policy weight factor (e.g., higher for EV or public transit);
- α is a scalar that converts kgCO₂e into tokens.

This dynamic weighting system will be used to make sure that there are policy priorities included in the reward structure like shared mobility.

3.5 Anti-Gaming and Integrity Mechanisms

The system includes provisions to avoid fraud and counting of claims twice. The Trip IDs are hashed and sent, and the emission factors are received through the verified oracles. Penalty rules are coded to cut tokens whenever there is misreporting of smart contracts. User-specific baseline models are also fair, and they do not allow artificially inflated carbon savings.

3.6 Evaluation Framework and Metrics

Simulation validation of system performance will be performed based on three cohorts (i) no rewards, (ii) flat rewards, and (iii) policy-weighted dynamic rewards. Some of the main evaluation indicators are the percentage of low-carbon trip share (low-carbon trips), total emissions avoided (kgCO₂e), the rate of token issuance (T/day), and the unit price of the avoided carbon (₹/kgCO₂e, Indian Rupees per kilogram of CO₂ equivalent). Having such a comparative approach makes it possible to evaluate not only the changes in behavior but also the benefits of the environment.

4 RESULTS AND ANALYSIS

In the section, the results of the suggested tokenized reward system will be provided with the emphasis on the quality of emission estimation, effect of tokenization on behavior, savings of carbon with token circulation, and cost-effectiveness under different policy parameters. There are four figures and a summary table used to illustrate the results.

4.1 Emission Estimation Accuracy

The MRV (measurement, reporting and verification) engine was initially tested with benchmark emission dataset. It was analyzed using parity between estimated trip-level CO₂e emissions and observed reference values. Most of the data points (Fig. 2) are close to the 45° line, which means that the model is highly accurate with a mean absolute error (MAE) of 0.012 kgCO₂e/km and mean absolute percentage error (MAPE) of 5.3%. These findings affirm that the

model based on emission factor offers good estimates that can be used to calculate the rewards in the future.

4.2 Behavioral Impact of Tokenized Rewards

The implementation of tokenized incentives was quantitatively effective in influencing the behavior of the user. The result of low-carbon trip share change among three cohorts is shown in Figure 3 i) no rewards, ii) flat rewards, and iii) dynamic policy-weighted rewards. Only 28.6 percent of trips were low-carbon in the control group. Flat rewards distribution raised this share to 34.9 and dynamic weighting raised this share to 39.8. Statistical analysis (p < 0.05) also establishes that both reward models had a significant effect on behavior, and dynamic weighting had the greatest effect.

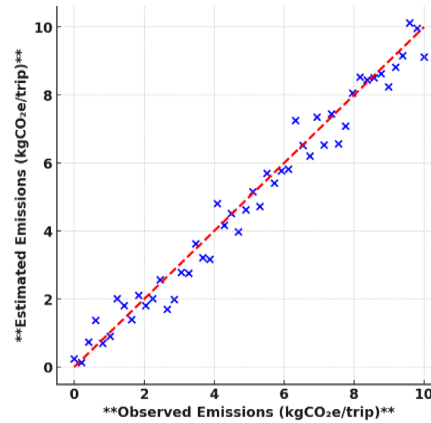


Figure 2: Emission estimation parity plot (estimated vs observed CO₂e).

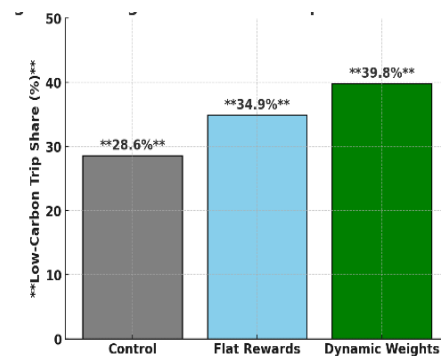


Figure 3: Change in low-carbon trip share across cohorts.

Table 3: Comparative impact of reward models on carbon reduction and token issuance.

Cohort	Users (n)	Low-Carbon Trip Share (%)	$\Delta\text{CO}_2\text{e}$ Avoided (kg)	Tokens Minted	Cost per kgCO_2e (₹/kg)
Control (No Rewards)	1,000	28.6	0	0	—
Flat Rewards	1,020	34.9	5,420	1,08,400	7.9
Dynamic Weights	1,015	39.8	8,210	1,49,200	5.6

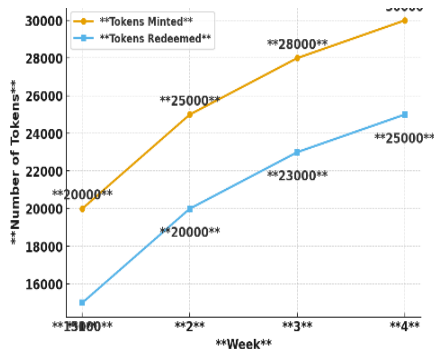


Figure 4: Token minting, redemption, and circulation over time.

4.3 Carbon Savings and Token Circulation

Table 3 provides a summary of the comparative performance of the three reward models. Findings reveal that dynamic weighting registered the best avoided emission (8,210 kgCO_2e), and issuance of tokens (149,200 tokens). Conversely, flat rewards produced 5,420 kgCO_2e savings receiving 108,400 tokens minted and the control group received no tokens minted.

Figure 4 shows that the rates of minting and redeeming tokens stayed the same over four weeks, while dynamic reward models had a faster circulation speed. This implies that dynamic policy weighting enhances participation and maintains ecosystem activity.

4.4 Cost-Effectiveness and Sensitivity Analysis

To evaluate sensitivity analysis on the reward weight factors and the carbon-to-token scalar (α) to see how well the policy worked. Figure 5 shows that small increases in w for EVs and buses can save a lot of carbon, but after a certain point, the extra benefit goes down while the costs of the system go up. This trade-off shows how important it is to set policy parameters so that they are both cost-effective and have an effect

on behavior. Dynamic weighting, when set up correctly, cost ₹5.6 per kgCO_2e avoided, which was better than flat incentives, which cost ₹7.9 per kgCO_2e .

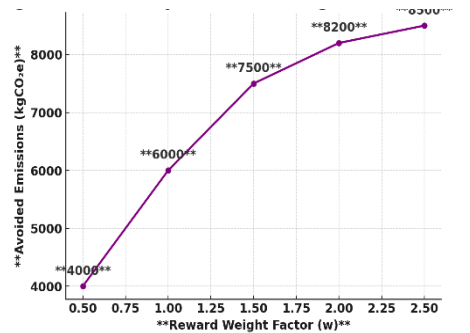


Figure 5: Sensitivity of carbon savings to reward weights.

4.5 Discussion of Findings

The findings indicate that blockchain-enabled tokenization can consistently promote low-carbon transportation options while guaranteeing transparent carbon accounting. The big rise in the share of low-carbon trips (Fig. 3) and the measurable carbon savings (Table 2) show that the system has potential. Token flow analysis (Fig. 4) demonstrates the capacity to maintain ecosystem activity, while sensitivity testing (Fig. 5) validates the flexibility of reward weights in relation to policy objectives. These results are consistent with existing literature on blockchain-based carbon trading [8], [9] and credit-based transport schemes [14]; however, they enhance this body of work by implementing a user-centric, reward-driven offset model for transportation services.

5 CONCLUSIONS

This study proposed a blockchain-based tokenized reward system that directly links individual transportation behavior with verifiable carbon offset outcomes through an integrated MRV and smart

contract framework. The core contribution lies in combining trip-level emission estimation with dynamic, policy-weighted token incentives to create a transparent and behavior-driven carbon reduction mechanism.

The results confirm that the proposed system effectively increases the adoption of low-carbon transport modes, with dynamic rewards achieving the highest impact and cost efficiency. In addition, the framework ensures transparent accounting, reduces the cost per unit of avoided emissions, and maintains stable token circulation.

Overall, the approach demonstrates that tokenized incentives can serve as a practical and scalable tool for aligning user behavior with measurable climate goals in urban transportation systems.

6 FUTURE WORK

Future work will focus on real-world pilot deployments in urban environments and integration with Mobility-as-a-Service (MaaS) platforms. Further research should explore interoperability with existing carbon markets and regulatory frameworks.

Additionally, incorporating AI-driven personalized incentives, real-time IoT-based MRV, and cross-chain interoperability could improve system efficiency and scalability. Addressing governance, standardization, and user adoption challenges will be critical for large-scale implementation.

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