Trust Framework for AI-Based Carbon Reduction Activity Certification

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***Abstract*—The accelerating carbon emissions crisis demands verifiable, sustainable mechanisms for individual carbon reduction. Existing digital platforms often rely on manual or self-reported verification, which limits credibility, scalability, and resistance to falsification. This study presents an AI-based, participatory framework for carbon-reduction activity certification that integrates automated image analysis with blockchain-based data anchoring. The proposed system employs artificial intelligence to validate user-submitted evidence of eco-friendly actions and stores verification results on the PureChain blockchain as immutable cryptographic hashes, ensuring transparency, traceability, and tamper resistance. By eliminating operator dependency, the framework enhances the trustworthiness and accountability of environmental data certification. Experimental validation confirms its feasibility under real blockchain conditions, achieving privacy preservation and efficient verification. The results establish a secure and scalable foundation for reliable AI-driven environmental certification, advancing digital trust frameworks for sustainable carbon-reduction ecosystems.**

***Index Terms*—Carbon reduction, AI-based activity verification, Data integrity, Blockchain, PureChain**

I. Introduction

The continuous increase in global carbon emissions has emerged as one of the most critical environmental challenges [1]. According to the National Oceanic and Atmospheric Administration (NOAA), atmospheric carbon dioxide concentrations exceeded 430 ppm in May 2025, the highest level ever recorded. This indicates that the planet is facing a severe crisis characterized by climate change and ecological imbalance [2].

In response, countries around the world are actively pursuing various strategies to reduce carbon emissions [3]. Corporations are adopting sustainable management frameworks to support eco-friendly operations and achieve carbon neutrality, while governments are strengthening policy measures and environmental regulations in line with international agreements. At the individual level, people participate in environmental protection through daily practices such as using tumblers, utilizing public transportation, and reducing single-use products [4], [5]. However, despite increasing awareness of climate change, many individuals struggle to recognize practical methods for reducing carbon emissions or to sustain eco-friendly practices over time [6]. This suggests that awareness alone is insufficient to drive long-term behavioral change, and that a systemic mechanism capable of maintaining individual participation is necessary [7].

To address this challenge, this study proposes an AI-based system for verifying carbon-reduction activities that enables users to perform eco-friendly behaviors and record them voluntarily. Users conduct various carbon-reducing actions in their daily lives and upload corresponding images. The system automatically verifies whether the submitted images accurately reflect eco-friendly actions through AI-based analysis [8]. While existing participation-driven environmental platforms also provide verification procedures, most rely on manual review or self-report mechanisms, which limit reliability and fairness. Since user-submitted activity data can be manipulated or falsified [9], a technical solution is required to ensure the integrity and trustworthiness of the records

To complement this limitation, this study introduces a structure in which AI verification results are hashed and stored on the PureChain blockchain. Leveraging blockchain's immutability and transparency, the system guarantees that activity records cannot be tampered with and allows anyone to verify later whether the original data has been altered [10], [11]. This approach addresses the reliability limitations of existing participation-based eco-platforms and establishes a verifiable record system for carbon-reduction activities.

This paper presents an AI-based mechanism for verifying carbon-reduction activities, combined with a blockchain-based integrity assurance structure [12], [13]. The objective is to create an environment in which user activity data are transparently managed without modification or corruption. Furthermore, the proposed system aims to serve as a scalable, sustainable carbon-reduction platform capable of effectively reducing ring per-capita carbon emissions in the long term.

II. Related Work

Carbon-reduction participation platforms have recently emerged as an essential means of promoting environmental protection and fostering sustainable lifestyle habits [14]. Public-sector programs such as the Carbon-Neutral Lifestyle Challenge in Korea and the Seoul Eco-Mileage Program encourage user participation and provide incentives for eco-friendly activities [15]. In the private sector, various reward-based platforms such as Challengers and CashWalk are also in operation, contributing to behavior change by motivating users through participation-based reward structures [16].

However, most existing systems primarily rely on self-reporting or manual verification processes. User-submitted

TABLE I: Comparison of existing carbon-reduction participation platforms

System	Verification Method	Data Management	Limitation
Carbon-Neutral Lifestyle Challenge	Manual review	Centralized server	Operator reliance, scalability limits
Seoul Eco-Mileage	Utility data submission	Centralized server	Limited to energy records
Challengers	Self-report via images/check-ins	Centralized server	Possible falsification, low trust level
CashWalk & reward apps	Activity tracking	Centralized server	Not designed for environmental proof

Note: Existing platforms rely on centralized architectures and lack automated verification and immutable record guarantees.

images and activity records are typically verified by platform administrators or reported by users, rather than automatically validated. As a result, these systems face challenges such as the potential for fraudulent data submissions, inefficiencies in manual review processes, and concerns about the platform operator's trustworthiness [17]. Furthermore, because activity data is stored on centralized servers, there is a risk of modification or deletion, and there is no mechanism for third-party verification; thus, the integrity of user activity records cannot be fully guaranteed [18].

In addition, many existing platforms lack mechanisms to quantify the actual environmental contribution of activities. Their reward structures are often based on participation frequency rather than on verified ecological impact, making it difficult to sustain engagement. While such systems may serve as practical tools for short-term behavioral motivation, they nonetheless have limitations in supporting long-term behavioral change and in providing fair, verifiable proof of eco-friendly actions [19].

These observations highlight the need for a new carbon-reduction participation system equipped with automated verification mechanisms and tamper-resistant activity recording. Table 1 compares existing systems in terms of their verification method, data management structure, and inherent limitations, thereby reinforcing this need. Therefore, to address the limitations of existing platforms, a system that integrates AI-based automatic verification with blockchain-based data-integrity protection is required for fair, transparent, and trustworthy carbon-reduction activity certification [20], [21].

III. AI-BASED PARTICIPATORY CARBON REDUCTION ACTIVITY CERTIFICATION AND DATA VERIFICATION SYSTEM

Users can participate in or create carbon-reduction challenges through a mobile application and submit images as evidence of activity participation. The submitted images are analyzed through AI-based inference to assess whether the visual content of the image corresponds to the predefined activity type, rather than to assert the absolute authenticity of the action.

In the proposed system, AI inference is performed using the Google Cloud Vision API, a commercial image recognition service. Specifically, the system employs the label detection functionality of the Vision API to obtain activity-related visual labels and their corresponding confidence scores, which serve as key inputs in the verification decision process.

Algorithm 1: AI-Driven Verification Algorithm Architecture

Input: I_{act} (activity image), T_{act} (activity type), U_{id} (user ID), t (timestamp)
Output: R_{ver} (verification result)

```
U ← GetUser(U_id)
R ← LoadRule(T_act)
I_up ← CaptureImage(U, I_act)
A_res ← AI.Verify(I_up, R)
if A_res.confidence ≥ R.threshold then
    if ValidateContext(I_up, R) then
        R_ver ← "approved"
        J_evd ← FormatJSON(U_id, T_act, t, A_res.confidence)
        H_evd ← SHA256(J_evd)
        AnchorOnChain(H_evd) // Smart contract emits verification event
        DisplayFeedback("approved", A_res.confidence)
    else
        R_ver ← "rejected (context validation failed)"
        DisplayFeedback("rejected", A_res.confidence)
else
    R_ver ← "rejected (low confidence)"
    DisplayFeedback("rejected", A_res.confidence)
return R_ver
```

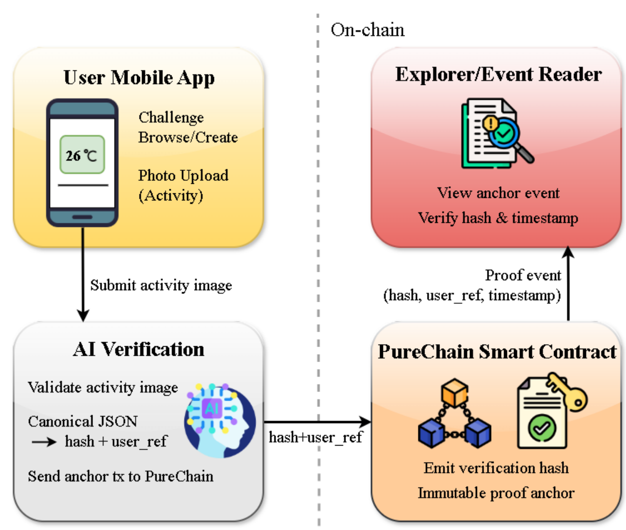

Fig. 1: The overall architecture of the proposed system

To reduce the risk of false approvals that may arise from relying solely on AI confidence scores, the proposed framework integrates rule-based context validation with AI inference results. Each challenge type is associated with a predefined set of rules, including required visual cues and minimum confidence thresholds. A verification decision is approved only when both the AI confidence threshold and the context validation rules are satisfied. This combined approach helps mitigate trivial false approvals caused by ambiguous visual patterns or environmental noise during image capture.

When an activity is approved, the verification result is organized into a structured JSON record containing the user identifier, activity type, timestamp, and AI confidence score. Instead of storing raw image data directly on the blockchain, the system computes a SHA-256–based cryptographic hash of the JSON record and anchors it on the blockchain network. This design preserves user privacy while ensuring data integrity and tamper evidence, and it minimizes on-chain storage costs and overhead.

Algorithm 1 presents the step-by-step workflow of the proposed AI-based verification procedure. First, the system loads the rule set corresponding to the user identifier and activity type, and then performs Vision API–based inference on the captured or uploaded image to obtain confidence scores for activity-related labels. Context validation is executed only if the confidence score exceeds the predefined threshold. If both the confidence threshold and context validation are satisfied, the system generates an approval result, constructs a JSON verification record, computes its SHA-256 hash, and anchors it on the blockchain. Otherwise, if the confidence score is below the threshold or context validation fails, a rejection result is returned and feedback is provided to the user. This verification logic combines AI inference with rule-based validation to ensure consistency and reliability in certification decisions.

Figure 1 illustrates the overall system architecture and data flow. When an activity image is submitted through the user's mobile application, the verification module constructs a JSON-based evidence record and computes its hash only in the case of approval, which is then anchored to the PureChain smart contract. The blockchain stores only hash-based proof data rather than raw images or sensitive information. External verifiers can retrieve anchoring events through an explorer or event listener and verify record integrity by recomputing and comparing hashes of off-chain JSON records. This architecture separates AI-assisted decision-making from blockchain-based integrity assurance, enabling both privacy preservation and scalability in real-world deployments.

A. User Participation and Authentication Interface Configuration

This system provides a mobile-based challenge mechanism that allows users to define and participate in their own environmental protection activities. Users can create new challenges or join existing ones within the application, entering details such as the challenge title, activity type, and duration during creation. The submitted information is displayed on the app's interface, prompting the subsequent authentication process. Figure 2 shows an example of the challenge creation screen.

When a user completes a challenge, they can take or upload a photo in the authentication screen. The system analyzes the submitted image through an AI model to determine whether the activity has been performed. The AI calculates a confidence score for the input image, and if it exceeds the predefined threshold, the certification is approved. If the confidence is below the criteria, certification is rejected, and the user may retry. For external verification, the approved authentication record is hashed and saved on the blockchain. This structure allows verification of any changes without storing the entire data, ensuring reliability.

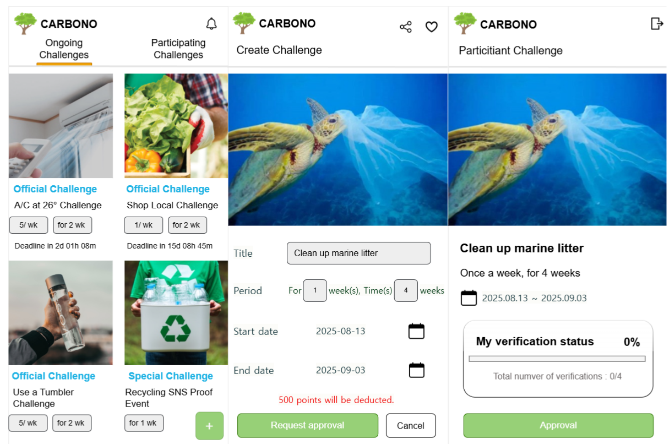

Fig. 2: Challenge Creation and Participation UI Screen

B. The blockchain-based authentication result anchoring procedure is as follows

The system applies an anchoring method that records the hash value of the verification log on the blockchain to ensure the reliability and reproducibility of AI authentication results. When a user submits an authentication image, the AI verifies it in an off-chain environment and returns the corresponding result as JSON. This JSON data undergoes key-order normalization, and then a SHA-256 hash is generated. Finally, the hash value is recorded on-chain through a smart contract event.

The demonstration phase involved step-by-step verification of the AI authentication and blockchain recording process. Based on authentication results collected through the app, verification data in the same format was anchored to the blockchain, confirming that the proposed method operates correctly in a real network environment. In this process, original images and personal information are not stored on the blockchain; only the hash values and pseudonymized user information are recorded in event logs. This design simultaneously achieves personal data protection and low-cost blockchain operation.

The on-chain structure uses an event-driven architecture and does not store state variables. Therefore, using the same input JSON, the hash can be regenerated to verify the integrity of the records. This lightweight proof structure provides tamper-proof protection without storing the entire dataset on-chain.

Figure 3 shows the screen where a smart contract was deployed in the PureChain environment using Remix, and Figure 4 displays the VerificationAnchored event logs created on the blockchain by calling the anchorVerification function through a separate backend script. This confirmed that the proposed verification log anchoring method operates correctly in a real blockchain environment.

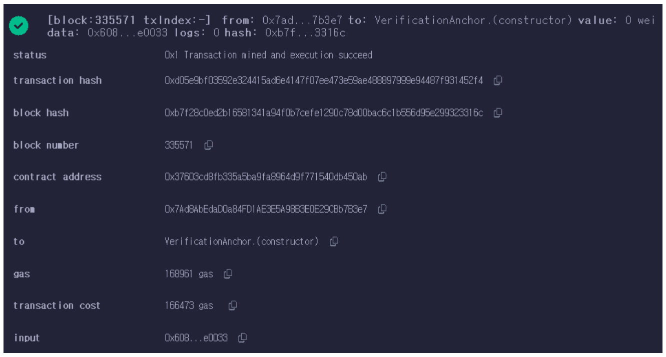

Fig. 3: PureChain Smart Contract Deployment Screen

Fig. 4: Generated On-Chain Event Logs

This experiment demonstrates that reliable authentication evidence can be provided without storing the entire authentication data. In the future, by integrating AI authentication with real-time on-chain recording, the system can be developed into a fully automated carbon-reduction certification framework.

IV. Conclusion and Future Work

This paper proposes an AI-based framework for verifying and validating participatory carbon-reduction activities to ensure the reliable execution and management of individual carbon-reduction efforts. When a user submits an image of a carbon-reduction activity, the AI model verifies its authenticity, and the resulting hash is stored on the blockchain, demonstrating the feasibility of preventing tampering and ensuring data transparency. Through this approach, the study presents technical potential and experimental evidence for mitigating limitations of existing platforms, such as reliance on manual verification, susceptibility to false submissions, and trust issues inherent in centralized data management. The proposed structure enhances the reliability of AI-based verification and establishes a trustworthy logging mechanism for eco-friendly actions, thereby forming a technical foundation for sustained user participation.

Future work will introduce a digital certificate issuance feature based on verified activity records, enabling formal proof of users' environmental contributions. A blockchain explorer-driven visualization function will also be developed to further enhance transparency by enabling intuitive verification of recorded results. In addition, real-world data collection across diverse carbon-reduction activities and continued advancement of the AI model will strengthen verification reliability. At the same time, long-term pilot studies will analyze user behavioral changes and evaluate the potential for the system to evolve into a scalable, sustainable carbon-reduction ecosystem.

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