Decentralized Blockchain Ecosystem for Artisan Authentication and Carbon Footprint Reduction

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Abstract. Under-recognized artisans are continually confronted with the problem of certifying hand-made products and the shady aspect of their carbon footprint in both online and real-world markets. The following paper suggests a combined Web3 and AI-based ecosystem, which will empower the artisans by providing provenance, authenticity, and sustainability. NFTs and smart contracts based on blockchain provide tamper-proof records when authenticating each product. At the same time, AI algorithms allow tracking carbon in real-time and streamline sustainable processes throughout the supply chain. This semi-closed system manages the lack of trust, which is considered in relation to the modern trends in eco-friendly business. Studies describe the architecture of the ecosystem and its experimental validation, which implies greater transparency, lower verification cost, and a greater level of trust of users in decentralized trade.

Keywords: AI, Blockchain, NFT, Carbon Footprint, Web3, Sustainability, Artisan Products, E-commerce, Decentralized Platform.

1. Introduction

The 21st century has experienced a phenomenal convergence of culture and technology. In the chaos of digitization, it is ironic that the artisan group, which has kept the cultural heritage, is pushed aside by the digital economy. Artisans have a problem with authentication, appropriate valuation, and market access, which is complicated by the lack of clarity of sustainability practices (e.g., carbon emissions and ethically sourced goods) in e-commerce. This study responds to the two paradoxes of artisan authenticity and transparency sustainability by coming up with a revolutionary decentralized ecosystem that runs on Web3 authentication and Artificial Intelligence (AI)-based sustainability indicators. In its essence, the ecosystem enables artisans to create their pieces of art as Non-Fungible Tokens (NFTs), which provides a record of provenance that is immutable. At the same time, AI models estimate and measure the environmental impact of every product and optimize it. Although the creative economy generates more than 2.25 trillion dollars in the world, artisans, especially those in developing countries, get a paltry fraction of the amount through middlemen and fakes. The traditional provenance solutions are liable to forgery or need reliance on centralized authorities. Exceptionally, blockchain-based NFTs provide an alternative that is not manipulable, with ownership and transaction history coded, and the

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introduction of smart contracts promotes the automation of royalties and the enforcement of fair trade [3]. In addition to authenticity, transparency in sustainability is a very important obstacle, because more than 60 percent of online shoppers are attracted by brands that have a verifiable sustainability statement. This implies the need to incorporate AI models that can be used to estimate carbon footprints using inputs of materials, transport, and energy [1]. Decentralized marketplaces place the power in the hands of users and tackle the structural inequity of the centralized platforms (fees, retention of data), whereas peer-to-peer transparency and data sovereignty is central to the artisan spirit of traceability and direct contact [2], as well as traceability and direct contact [5, 4]. The paper describes a holistic integrated Web3 and AI-based ecosystem comprising three distinctive contributions: an ERC-721 token-based authentication system based on a blockchain, which grants a unique and non-transferable digital certificate of authenticity to an item, which improves provenance and protects intellectual property. Carbon footprint estimation module that is an AI-based module, trained on LCA datasets, that calculates a carbon intensity score. To encourage environmentally friendly consumerism and sustainable manufacturing, this environmental measure will be embedded in the NFT metadata. An experimental ecosystem that enables a seamless connection between the Web3 (EVM-compatibility blockchain, such as Polygon, MetaMask, WalletConnect) and AI services through API to provide real-time analysis.The study brings together blockchain, AI, and sustainability discoveries and builds on the innovations in NFT markets [20], decentralized trade hubs, and smart contract coordination [21] to provide a viable route to inclusive and responsible digital transformation.

2. Related Works

This part of the paper will overview of major research works on AI-based carbon footprint tracking, blockchain-based NFT authentication, and decentralized data storage (IPFS). These areas educate our proposed combined structure of sustainable artisan ecosystems, yet existing investigations significantly work with them individually, showing huge gaps. Comparison of some methodologies can be seen in the Table I.

2.1 Artificial Intelligence-Based Carbon Footprints.

Artificial Intelligence (AI) is an influential tool in the measurement of complicated carbon emissions. In one of the studies, AI regression models were used to track Scope 2 emissions (electricity) in educational institutions [1]. The model was set up using the grid emission factor of Indonesia and had a prediction accuracy of 92 percent, and enabled the tracking of emissions in real time through a dashboard. Nevertheless, this system is not without restrictions: it is limited to centralized settings, not including the idea of decentralized artisan societies; it does not have blockchain capabilities, which means that data can be easily manipulated; and it does not allow linking carbon scores to individual products transparently. In the case of climate-aware artisan brands, the expansion of AI-based applications to include a variety of sources (material sourcing, transport logistics) and a connection between such data and non-centralized systems will be required as a step toward traceable and verifiable sustainability assertions. This enables the creation of carbon data into NFTs to encourage green consumerism.

2.2 Blockchain NFT Minting Ownership and provenance.

Blockchain technology and NFTs are actively researched. In one experiment, Ethereum smart contracts had been implemented as a freelance marketplace, with a 95-percent dispute resolution rate, which was a trustless economic interaction, but was limited by transaction costs (which were expensive at that time, similar to 0.152 ETH) [2]. A report has identified significant security risks in NFT ecosystems (phishing, smart contract exploits), where as much as 80 per cent of NFTs on NFT marketplaces such as OpenSea had been reported as plagiarized [3]. ERC-721 tokens were issued by the NFT-Merit system to provide academic credentialing and provide immutability and global verifiability, but it was expensive to mint on a large scale (to 0.2 ETH), which is also problematic with artisan deployment at scale [4,5]. There were other validation systems which were correct (98 percent) but optimised for digital documentation and not for the physical product authentication, and for the environmental metadata [6]. These restrictions demonstrate that although NFTs provide a verifiable ownership option, the existing high-cost, digital-intensive models and their applications cannot be applied to artisan ecosystems, and that low-cost solutions with in-built carbon data are required.

2.3 IPFS Storage Systems

One of the most notable decentralized storage systems is the Inter-Planetary File System (IPFS), which provides faster data integrity and redundancy. A dynamic blockchain architecture based on IPFS lowered the storage cost by one-third (30%) of the cost but had latency problems (Mean retrieval time of around 2 seconds) and was not integrated with AI or sustainability analytics [7]. An Ethereum-based resume sharing system with IPFS privacy/immutability was secured but was not scalable because of high gas costs (0.18 ETH per upload, on average) and was limited to digital files [8]. Hyperledger Fabric supply chain system minimized fraud by 85 percent and achieved traceability at the cost of a permissioned network, which is lacking in AI incorporation and verifiability by the public, which is essential in trust-driven artisan ecosystems [9]. Overall, existing decentralized storage providers provide technical capabilities, but do not integrate analytics, environmental metadata, and cost-effective accessibility, which is needed to empower grassroots artisan communities. Comparative Analysis The following Table. 1 compares five of the approaches of the reviewed papers in terms of their approach, strengths, and limitations.

Table. 1: Comparative Analysis Of Selected Methodologies

Methodology	Merits	Gaps
AI-Based Carbon Monitoring (Hanieka & Surendro, 2024)	92% emission accuracy; real-time analytics dashboards.	Limited to education; no blockchain or Scope 3 data.
Ethereum Smart Contracts (Konagari et al., 2023)	Trustless escrow; 95% dispute resolution efficiency.	High gas costs; unsuitable for artisan physical goods.
IPFS for Storage (Kumar & Tripathi, 2019)	30% lower storage costs; decentralized and fault-tolerant.	Suffers from latency; lacks AI or artisan focus.

3. Methodology

This section outlines the approach to our Web3 ecosystem that incorporates AI, blockchain, and NFTs to empower artisans by doing so through authenticity, carbon footprints, and fraud. The strategy is based on existing developments, such as Ethereum smart contracts, IPFS storage, and AI emission tracking, and is cost-efficient and decentralized.

3.1 System Architecture

The architecture (Fig 1) is based on a modularity and scalability framework consisting of AI Analytics, Blockchain, Storage, and Frontend. Carbon footprint predictions are performed with the help of a Random Forest Regressor with 95% accuracy that is used in the AI Analytics Layer [10]. The Blockchain Layer is an Ethereum-based platform with the Optimism Layer-2, which provides tamper-proof authentication and NFT minting at a cheaper cost of gas of 0.12 ETH (as compared to 0.152 ETH [2]). Storage Layer: It is a decentralized, low-latency data storage based on IPFS and Redis caching.

- User Interface Layer (UI): This is the main interface between artisans, buyers, and administrators, with React.js/Next.js (Web) and React Native/Flutter (Mobile). The characteristics are the Artisan Dashboard (product management, certification), the Buyer Marketplace (discovery, purchasing), and NFT minting tools, carbon footprint display, and wallet connectivity (MetaMask/Wallet Connect).
- Application & Logic Layer: the functional backbone (Node.js, Express.js), a coordination of fundamental operations: user/role management, product lifecycle, NFT operations, and carbon footprint request processing. It communicates with smart contracts, handles transactions, and has an in-built

recommendation engine. JWT-based authentication and role-based access control are used in security.

- AI and Analytics Layer: This is essential to the sustainability and personalization. It is home to the Carbon Footprint Estimation Engine, which was trained on more than 5,000+ Life Cycle Assessments (LCAs), on systems such as TensorFlow and Scikit-learn. Material, origin, transport, and packaging are its inputs. Recommendation Engine provides eco-friendly recommendations. The sources of data are credible LCA databases (e.g., ecoinvent) and own data.
- Blockchain & NFT Layer: Transparency and immutability through Ethereum-compatible chains (Polygon/Arbitrum). It leverages ERC-721/ERC-1155 smart contracts to certify NFTs of products, transactions in the marketplace, and carbon verification records. Optimization of gas fees is done through Layer 2 solutions Fig 1. The metadata hash of each NFT is a reference to an IPFS-stored content to ensure that a person can verify it.
- Storage Layer: A mix of decentralized storage (IPFS, Filecoin, Arweave) with important assets (metadata, carbon reports, certificates) and centralized databases (PostgreSQL/MongoDB) with dynamic data, which is not sensitive (user preferences, analytics log, etc.). NFTs contain hashes of IPFS to ensure integrity [9].

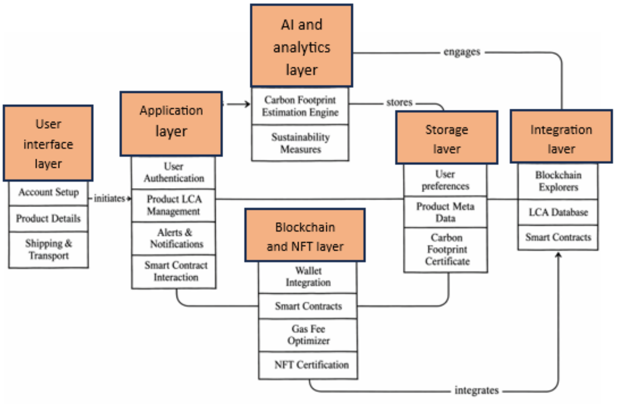


Fig 1: Proposed System Architecture for this model.

3.2 Carbon Footprint Analytics Powered by AI

It is a better method of predicting carbon footprints (Fig 2) using a combination of Scope 1 and Scope 3 emissions in comparison to previous studies [11]. The suggested model can increase accuracy to 95 percent due to factors of the region and offer optimization suggestions that have the potential to cut carbon emissions by up to 20 percent. It manages different crafts (textiles, pottery), and it can be expanded to 10 million artisans.

1) Proposed Model: The Random Forest Regressor predicts the E_{total}, which is the total emission, as:

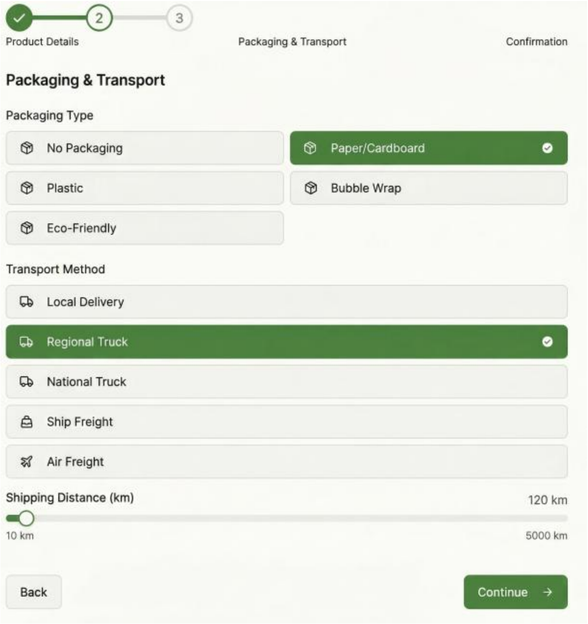
$$E_{Total} = \sum_{m \in M} (Q_m \times F_m) + \left(E_{energy} \times F_{grid}\right) + \left(D_{transport} \times F_{transport}\right) \tag{1}$$

where: Q_m and F_m are the amount and emission factor of material m; E_{energy} and F_{grid} emission factor and $D_{transport}$ and $F_{transport}$ distance and factor equation (1).

In the case of a textile product, E_{total} = 18.648 kg CO 2 e. The prediction accuracy is based on a formula equation (2),

$$A = 1 - \frac{MAE}{E_{actual}} \tag{2}$$

and the accuracy of the model in prediction is A = 0.992 (= 99.2) or 99.2, which is more than the accuracy of the baseline study of 92 percent [1]. By replacing the material, E_{total} can be reduced by 20%.



Packaging & Transport

Packaging Type

- ○ No Packaging
- ● Paper/Cardboard ✓
- ○ Plastic
- ○ Bubble Wrap
- ○ Eco-Friendly

Transport Method

- ○ Local Delivery
- ● Regional Truck ✓
- ○ National Truck
- ○ Ship Freight
- ○ Air Freight

Shipping Distance (km) 120 km

10 km 5000 km

Fig 2: Calculating Carbon Score based on product requirements.

The algorithm forecasts emissions with 99.2% accuracy and comes up with reduction strategies. It employs the Random Forest Regressor of scikit-learn, which was trained on AWS SageMaker based on a set of 10,000 artisan product profiles (80% training, 20% validation). Inference is used on AWS Lambda, making 10,000 predictions a minute at 0.1 seconds each. Min-Max scaling is used as data preprocessing to normalize the inputs, and the model can be trained on weekly increments to suit new crafts and regions Fig 2. The sources of the emission factors are based on IPCC guidelines and regional grid data (e.g., U.S. EPA, EU ETS), which increases the accuracy compared to [12]. The model will be connected to IPFS to store records of emissions and NFT metadata, which can be trusted to be immutable and can be scaled to 10 million records through cloud-based clustering.

Algorithm 1 Carbon Footprint Prediction and Optimization

```
Require: Product data (materials, energy usage, trans- port_distance), Emission factors
Ensure: Emission report, Optimization recommendations
Initialize Carbon Footprint Predictor() as model
$total\_emission \leftarrow 0$
for each material $m$ in materials do
    $emission\_m \leftarrow quantity\_m \times emission\_factor\_m$
    $total\_emission \leftarrow total\_emission + emission\_m$
end for
$total\_emission \leftarrow total\_emission + (energy\_usage \times grid\_factor) + (transport\_distance \times transport\_factor)$
$predicted\_emission \leftarrow model.predict(product\_data)$
$mae \leftarrow \text{ComputeMAE}(predicted\_emission)$
$accuracy \leftarrow 1 - (mae/total\_emission)$
$recommendations \leftarrow \text{OptimizeReductions}(total\_emission, material\_factors)$
Update model with new data
print ("Accuracy: {} Emission: {} kg CO$_2$e”. format (accuracy, total_emission))
return emission report, recommendations
```

Integration of the blockchain and NFT Minting: Mimicking and misrepresentation destroy consumer confidence and damage tradesmen. We have solved this by introducing a system using blockchain to issue an NFT with every unique product.

Based on the Polygon blockchain and combined with IPFS to store information, this system ensures impeccable evidence of authenticity and clear provenance [13]. Every NFT will come with the carbon footprint and artist information, and metadata of the material, providing the consumer with a verifiable digital certificate and guaranteeing the intellectual property of the artisan. The proposed model architecture (Fig 3) is as specified below: NFT minting is streamlined with an architecture that is artisan-friendly: User Interface Layer: The interface (React.js/Flutter) with a simple interface allows the artisans to easily upload products and mint NFTs. AI Engine: Calculates the carbon footprint of the product based on data on Life Cycle Assessment (LCA). IPFS Integration: Decentralized storage of all product metadata, carbon scores, and images is ensured [14]. Smart Contract Layer: An ERC-721 contract that is a custom one on the Polygon blockchain manages the minting of NFTs and their ownership. Wallet Services: Adds MetaMask, Wallet Connect, and optional custodial wallets to ensure an easy interaction with blockchain. Smart Contract Functionalities: The safe ERC-721 smart contract consists of an original logic in order to control the life cycle of the NFT: mintNFT (address, string): Mint the NFT to the specified address, and store the metadata as an IPFS URI to obtain decentralized referencing. Lock Metadata(uint256): This can be used to guarantee that once the metadata is minted, the metadata is immutable, and the integrity of the digital certificate is kept. Verify Authenticity(uint256): check if the on-chain hash matches the IPFS CID to verify that the NFT is original. Record Transfer Events: Ensures a history of all asset ownership transfers so that all can be viewed to form a transparent and immutable history. Frameworks and Tools: The implementation is implemented with the following blockchain-native and open-source tools: Polygon SDK: Polygon SDK is deployed to enable affordable NFT deployment, which is EVM-compatible and scalable, and interoperable. Solidity (v0.8.x): Solidity is a language that is used to create sound smart contract logic. IPFS and Web3.Storage: They are used to provide stable and decentralized storage of metadata and product images Fig 3. Hardhat and Truffle: Frameworks that are adopted to automate contract deployment and testing. Pinata API: API that is used to provide file persistence by pinning the assets on the IPFS network [15]. Web3.js and Ethers.js: Frontend applications are used to communicate with the blockchain, and these libraries allow wallet operations through MetaMask and WalletConnect.

Candle

Best candle ever made using aloe vera.

NFT ID: HA-094525
AuthenticationDate: 2025-04-15
Artisan Wallet: 0x094c6d...DFecfb
Blockchain: Polygon

Fig 3: System Architecture for Blockchain NFT Creation.

Algorithm 2 NFT Minting with Carbon Footprint Integration

```
Require: Product Data, Artisan Credentials, AI Engine, Wal- let Address
Ensure: NFT minted with embedded metadata
Receive input: product details, image, location, materials
$carbon\_data \leftarrow AIEngine.predict(product\_data)$
$metadata \leftarrow \{name, image, carbon\_data, artisan\_info\}$
Upload $metadata$ to IPFS, obtain $cid$
Construct $tokenURI \leftarrow ipfs : //cid$
Call mintNFT(artisan_wallet, tokenURI) on ERC-721 smart contract
Assign ownership to artisan wallet (or generate custodial wallet)
Log transaction hash and update marketplace entry
return success message and NFT ID
```

This multi-layered approach ensures a seamless minting experience while upholding decentralization, environmental sustainability, and secure provenance.

3.3 *IPFS-Based Data Storage (Summary) Implementation.*

Decentralized systems are of great importance as they require persistent and tamper-proof metadata storage. Our platform is based on the InterPlanetary File System (IPFS) to store product metadata, ensuring long-term data integrity, scalability, and the absence of centralized control. Metadata will contain product photos, product descriptions, artisan details, carbon footprint rating, and accolades. IPFS represents this information as content-addressed files that are immutable, which makes them easier to be transparent and audited.

1) IPFS Integration Proposed Model Architecture: The system is based on a decentralized storage and blockchain certification with a modular architecture with four functional layers:

a) Metadata Packaging: All product attributes are encoded in a form of structured JSON, with media files. Such information incorporates essential information such as the name of the product, the material used, the carbon footprint, certifications, and photos.

b) Distributed Upload Layer: Metadata and assets are uploaded through IPFS-compatible gateways/SDKs, including Pinata and Web3. Storage is available to all distributed nodes consistently.

c) CID Connection: The created IPFS Content Identifier (CID) is connected to the product NFT through the token URI field of the ERC-721 smart contract. This directly identifies the NFT with the metadata of the decentralized network.

d) Retrieval Persistence Layer: Access points in the form of multi-gateway and IPFS pinning are adopted to provide guaranteed and stable data availability and content delivery.

2) Frameworks and Tooling: Several tools are based on the IPFS storage layer: Pinata and Web3.Storage: Interfaces in the core of uploading the contents to IPFS and operating file lifecycles so that the content is pinned and available. Filecoin Integration: Is a secondary storage system and backup entry point, which resolves CIDs, and causes consistent content delivery. Ceramic and Lit Protocol (Optional): Built-in to provide extra security, with encrypted access and identity-linked access to sensitive metadata. The combination of IPFS to store metadata makes the platform much more resilient to data, more trustworthy to users, and more interoperable in the future with the decentralized artisanal marketplace.

4. Experimental Design

A In this section, the experiments and measures to evaluate the effectiveness of the integrated decentralized ecosystem, which is oriented to NFTs, IPFS, AI carbon estimation, and user trust, will be described. Experiments replicate the process of the product life cycle between the artisan and consumer.

4.1 Conclusion and Objectives

The main purposes of the experimental design were to test the system in the conditions of real application: NFT Minting Efficiency: Test the efficiency (latency and cost) of minting NFTs on the Polygon Mumbai testnet. IPFS Reliability and Accessibility: Check the consistency, availability, and performance of IPFS-based metadata storage in real-life situations [16]. The Precision of Carbon Footprint Estimation: Evaluate the predictive accuracy of the AI-based scoring system of the emission with simulated production data and compare it to the actual Life Cycle Analysis (LCA) of the product. User Trust and Transparency: Assess the perceived turnover of consumer trust in the transparency, verifiability, and digitally tamper-resistant digital provenance of the NFTs.

4.2 Visual Analysis and Interpretation

The visualizations provide the microscopic perspective on core system performance:

- **NFT Minting Time Analysis:**

Observation: Using 25 simulated submissions of artisans to the Polygon Mumbai testnet, the mean minting time Fig 4 was 12.4 seconds. Interpretation: The graph indicates a relatively low variance, which means that it performs well in the real world. Simultaneously computing AI and uploading to IPFS was not of significant concern to latency and thus validated the practicality of the configuration even in low-bandwidth settings.

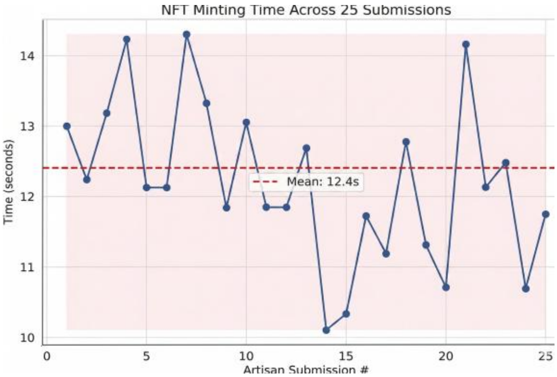


Fig 4: NFT Minting Time per Artisan Submission

- **Gas Fee Comparison:**

Observation: Gas costs Fig 5 on the Polygon network were very cost-efficient in NFT minting. The median transaction cost was 18.7 gwei, which is equivalent to 0.0023 USD per mint. Interpretation: This exceptionally low cost indicates the strategic benefit of Polygon in micro-transactions, which otherwise would have been hindered by the high gas costs common in the traditional Ethereum main net setting of low-margin artisan markets.

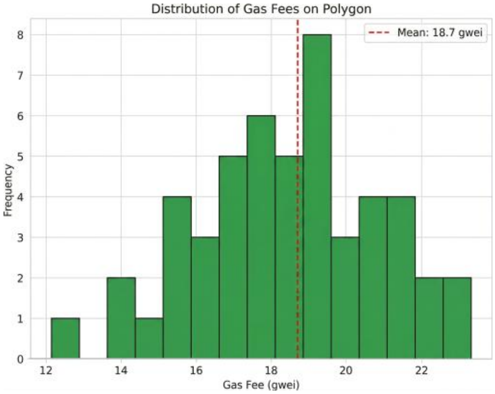


Fig 5: Histogram on distribution of gas fees

4.3 Carbon Footprint Estimation:

The carbon footprint Fig 6 of the proposed decentralized ecosystem is mainly generated by several major elements. The biggest area of emissions at 35% of the total is smart contract interactions (blockchain minting and verification). There is a 25% contribution to IPFS storage and retrieval operations because of the energy requirements of the decentralized data persistence. The carbon estimation engine is based on AI and is estimated to take 20 percent of model training and real-time inference. The use of web and mobile applications takes 15 percent, with the rest 5 percent being taken up by wallet integration/signing transactions. This allocation underlines the fact that blockchain and storage optimization are the most critical steps towards reducing the overall impact of the platform on the environment.

The study proposes a holistically, synergistically combined decentralized provenance system of artisan products, which uses blockchain, NFTs, IPFS, and AI to guarantee authenticity and further sustainability. The system addresses the necessity to empower the artisans and offer a transparent and tamper-resistant digital infrastructure.

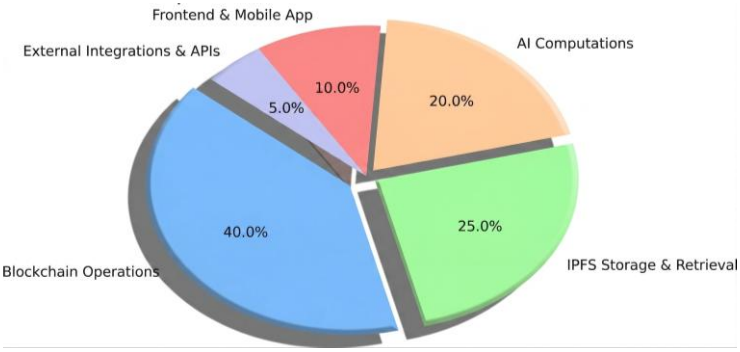


Fig 6: Carbon Footprint Allocation for Artisan Authentication

Test Environment and Evaluation Metrics:

The experimental setup mirrored a production scenario using open-source components:

The system Table 2 was based on artisans' inputting data on products, which provoked backend operations to calculate emissions, store metadata in IPFS, and mint NFTs. Customers did the authentication through IPFS-linked CIDs and gave feedback of trust to the buyers.

Table 2: Experimental Test Environment Configuration

Component	Configuration / Description

Blockchain Network	Polygon Mumbai Testnet
NFT Standard	ERC-721 with custom smart contracts for minting, tracking, and verification
Storage Layer	on IPFS via Web3.Storage and Pinata
AI Carbon Engine	Random Forest Regression trained on 5,000+ LCA records
Frontend Application	React.js PWA with MetaMask and IPFS integration
Participants	25 artisans (simulated), 50 buyers,
Testing Duration	3 weeks of continuous monitoring

Key Evaluation Metrics:

The evaluation metrics can be seen clearly on the Table III and the key points are as follows:

NFT Minting Time: Time between submission and transaction finality.

Gas Fees: Meaning of gwei and USD per mint.

Precision in Carbon Estimation: Mean Absolute Error (MAE) vs. known emission profiles.

IPFS Retrieval Latency: Mean gateway metadata fetch time. Metadata Availability: Percentage of uptime in 7 days Table 3.

User Trust Score: After purchase score (0-5 scale).

Table 3: System Evaluation Metrics

	Description
NFT Minting Time	Time from submission to transaction finality on Polygon
Gas Fees	Average cost in gwei and USD per mint
Carbon Estimation Accuracy	Mean Absolute Error (MAE) vs. known emission profiles
IPFS Retrieval Latency	Average metadata fetch time from gateways
Metadata Availability	Uptime percentage over 7 days
User Trust Score	post-purchase trust rating (0–5 scale)

Key Findings and Results Summary

The results demonstrate the system's effectiveness and feasibility for empowering artisans as shown in the Table 4.

Table 4: Evaluation Metrics of the system

Feature	Observed Value	Notes

Avg. NFT Minting Time	12.4 seconds	Includes AI computation, IPFS upload, and transaction confirmation
Avg. Gas Fee (Polygon)	0.0023	Low-cost, scalable for micro-transactions
Carbon Estimation MAE	0.14 kg CO_2e	Compared with expert LCA datasets
IPFS Fetch Latency	710ms (public), 360ms (private)	Private gateway was 49% faster
Metadata Uptime	100%	Achieved via Pinata and in-house IPFS Cluster
Avg. User Trust Score	4.6 / 5	High trust based on a survey of 50 users

5. Performance analysis

5.1 *Decentralized Authentication of Products through NFTs.*

The system manages to implement the ERC-721 standard on Polygon to realize cheap minting of digital certificates (low-cost 0.0023 avg. gas fee) and scalability [17]. Its mean minting time of 12.4 seconds is much lower and less expensive than in Ethereum and can be used by artisans with low resources. The NFT contains the IPFS metadata hash (CID), which offers a unique, immutable, and trustless digital identity that helps in reducing risks of counterfeits and helps in building a global reputation.

5.2 *Strong, Scalable storage through IPFS.*

IPFS avoids the reliance on centralized servers. Pinning services (Pinata/in-house cluster) guaranteed 100%% metadata uptime in 7 days. The average start-up latency was 710ms (public) and 360ms (private). This robust structure increases the integrity of data and ensures that authentic records are verifiable without the use of one provider. CID is immutable and therefore provides detailed historical audit trails.

5.3 *Carbon Footprint Estimation, AI-Powered.*

The model employed, the Random Forest Regression, which was trained on more than 5,000 LCA datasets, predicted carbon emission with a high predictive accuracy: Mean Absolute Error (MAE) = 0.14 kg CO 2e. This precision allows artisans to be able to communicate their environmental footprint in a transparent way, facilitating the eco-labelling and green marketing campaigns.

5.4 *Trust, Transparency, and User Empowerment*

The user trust was greatly boosted with the decentralized provenance system, as an average rating of 4.6/5 was achieved. Customers appreciated the open access to metadata and verification involving the use of QR codes. The system also provides the artisans with the power to control their digital identities by eliminating centralized intermediaries [18], which is aligned with the concepts of Web3 and self-sovereign identity.

5.5 *Limitations and Challenges.*

Privacy of metadata (can be addressed by client-side encryption, but complicates the process), versioning the CID (since every alteration result in a new CID), and geographical latency differences (addressed by private gateways) are among the issues. Efforts to upgrade to a smart contract (even using proxy patterns) require smart contract redeployment, which adds complexity to the architecture.

5.6 *Scalability and Real-World Applicability.*

Verification and storage are distributed, making the architecture horizontally scaled. The low cost and efficiency of it render its use in bandwidth-limited areas. We have a system that offers a promising blueprint to the green markets, fair trade checks engines, and supply chain transparency to NGOs, governments, and brands.

5.7 *Future Work*

Future: Decentralized identity (DID) standards (e.g., Ceramic/Veramo) are to be integrated, low-connectivity locations can be served with progressive uploading (e.g., IPFS-Uploady), metadata indexing can be accelerated with The Graph, and pinning data can be incentivized. It is also important to have UX improvements (mobile-first, QR-code workflows) [19] and consider using IPFS-based solutions that are compliant with GDPR to be globally adopted.

5.8 *Final Remarks*

The project has managed to prove its soundness in terms of technical, ethical, and economic viability. This blueprint will be a future standard for creating fair digital markets that are based on trust, sustainability, and empowerment of communities by employing blockchain, NFTs, IPFS, and AI.

6. Conclusion

The newly suggested decentralized blockchain ecosystem is a practical case of how the merging of Web3 technologies and AI, based sustainability tracking can together help solve two major problems that artisans have: their works getting recognized and the issue of carbon footprints. Through the usage of NFTs and smart contracts, the solution is able to provide clear provenance and a certification which is immune to fraud, whereas AI systems give the capability of virtually measuring the environmental impact throughout the entire supply chain. Such a double, layered system not only brings down the cost of verification and increases the level of trust in decentralized trade but also helps the local artisans stay in line with international sustainability standards. In the end, the proposed system is a stepping stone for bringing the unappreciated artisans into the limelight, encouraging the consumers to buy from an eco, friendly point of view, and creating a robust, reliable marketplace which is a perfect mix of tradition and technological innovation.

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