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A Blockchain-Based Framework for Decentralized Electric Vehicle Data Management

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Executive Summary

The fast-growing number of electric vehicles (EV) has led to the generation of considerable amounts of data daily, including information on charging behavior, trip information, and driving habits. To achieve optimal operation efficiency, user experience, and the development of data-driven services in the field of e-mobility, professional management of the data becomes inevitable. This paper proposes the Electric Vehicle Data Management Framework (EVDMF), a blockchain-based decentralized system that aims at ensuring data security, privacy, and transparency. In such a framework, the model of Decentralized Autonomous Organization (DAO) has been incorporated for collaborative governance to incentivize EV data sharing. EVDMF has aimed to establish a sustainable, secure, and efficient ecosystem for managing EV data with the involvement of EV drivers and Charging Point Operators (CPO) on the network.

Keywords: Electric Vehicles, Consumer Behaviour, Consumer Demand, Energy Management, Charging Business Models

1. Introduction

The rapid adoption of electric vehicles (EVs) worldwide is reshaping the landscape of transportation while simultaneously generating unprecedented volumes of valuable data. Efficient management of EV-generated data is essential for enhancing user satisfaction, facilitating the development of intelligent mobility solutions, new charging business models, and optimizing infrastructure utilization. Nevertheless, traditional centralized data management models expose users to significant risks, including security breaches, loss of data ownership, and erosion of trust. Blockchain technology emerges as a promising solution to these challenges by enabling decentralized, secure, and transparent data governance. Although prior research [1-4] has explored blockchain applications in energy trading, vehicle authentication, and autonomous mobility, there remains a notable gap in providing a comprehensive, collaborative EV data-sharing ecosystem that effectively integrates incentives and decentralized governance mechanisms.

This paper aims to address the following research question: how can blockchain and decentralized governance be leveraged to create a secure, privacy-preserving, and incentive-aligned framework for EV data management? To this end, the paper proposes the Electric Vehicle Data Management Framework (EVDMF), a novel architecture that combines Decentralized Autonomous Organization (DAO)-based governance, and a tokenized incentive system to foster a secure, efficient, and equitable EV data ecosystem.

2. Related Work

Prior research efforts have increasingly explored the application of blockchain technology within the context of energy systems and vehicular networks, yielding promising results in specific operational domains. Notably, several studies have concentrated on blockchain-based energy trading models within vehicle-to-grid (V2G) environments. In these frameworks, blockchain is employed to facilitate decentralized, peer-to-peer energy transactions, enabling EV owners to sell excess battery energy back to the grid or to other consumers in a secure way [1]. Other works have proposed hierarchical authentication mechanisms utilizing blockchain to enhance the security and trustworthiness of communication between electric vehicles and distributed energy resources [2]. Furthermore, blockchain solutions have been explored in autonomous vehicle ecosystems, where distributed ledger technology is leveraged to enable situation awareness, service cooperation, and secure information exchange among vehicles and infrastructure nodes [3]. While these contributions demonstrate the viability of blockchain as an enabler of secure, decentralized operations in mobility and energy systems, they share several fundamental limitations when viewed from the broader perspective of comprehensive EV data management [4]. Initially, most existing studies are narrowly scoped, addressing only specific technical problems such as transaction verification, authentication, or localized data sharing. As such, they do not manage to propose a holistic architecture capable of encompassing the diverse and dynamic interactions among a wide array of stakeholders [5] in the EV ecosystem, including EV users, Charging Point Operators (CPOs), automotive manufacturers, utility providers and grid operators.

Moreover, prior research largely neglects the critical dimension of participant motivation and economic alignment. In decentralized environments, the willingness of stakeholders to contribute valuable data or services cannot be presumed; rather, it must be actively incentivized through carefully designed economic mechanisms [6]. Current blockchain-based models in the EV sector rarely incorporate robust incentive structures, resulting in systems that may be technically sound but socially and economically fragile. Without tangible rewards or benefits, stakeholders have little reason to participate, particularly when sharing data could expose them to competitive disadvantages or privacy risks. Most existing frameworks insufficiently address the tension between data sharing and intellectual property protection. Vehicle manufacturers, charging hardware companies, and service providers often regard their collected data as strategic assets critical to maintaining competitive advantage. A framework that encourages open data exchange must therefore embed governance mechanisms that allow stakeholders to manage access, define usage policies, and retain control over sensitive information.

Recognizing these gaps, this study proposes the EVDMF as a novel and comprehensive solution. The EVDMF distinguishes itself from previous approaches in several key dimensions. First, it introduces a governance model based on Decentralized Autonomous Organizations (DAOs), wherein stakeholders collectively manage the network's rules, access permissions, and operational protocols through transparent, immutable smart contracts [7]. In contrast to centralized systems, where decision-making power is concentrated in the hands of a few entities, the DAO model ensures that all participants have a voice proportional to their contribution and engagement within the system [8]. Second, the EVDMF incorporates a tokenized incentive mechanism that directly aligns individual stakeholder incentives with the collective health and growth of the network. EV drivers earn tokens in exchange for their data sharing, which can be redeemed for charging discounts. Charging Point Operators and service providers, in turn, utilize tokens to access high-quality, authenticated datasets that can enhance their operational efficiency and customer offerings [9]. By embedding economic incentives at the core of the framework, EVDMF fosters a self-sustaining ecosystem characterized by continuous participation and mutual benefit. Third, by leveraging blockchain pseudonymity, encryption techniques, and possibly advanced privacy-preserving technologies, the framework ensures that participants can share data without compromising their personal or corporate confidentiality. This design choice not only addresses regulatory concerns (e.g., GDPR compliance) but also lowers psychological barriers to participation by reassuring stakeholders that their sensitive information remains protected.

3. Proposed Framework

The EVDMF is designed as a comprehensive, decentralized system that systematically addresses the challenges associated with electric vehicle (EV) data management. The framework is structured around three fundamental pillars: the blockchain-based data layer, the decentralized governance mechanism based on DAOs, and an integrated incentive system that ensures sustained stakeholder engagement and economic sustainability. Each of these pillars contributes synergistically to achieving EVDMF's core objectives of enhancing data security, preserving user privacy, fostering stakeholder trust, and building a self-sustaining ecosystem for EV data sharing.

3.1 Blockchain Layer: Secure and Scalable Data Management

At the technological foundation of the EVDMF lies an ETH Layer 2 sidechain (Polygon). This blockchain serves as the backbone for ensuring that all data transactions within the system are secure, immutable, transparent, and verifiable. Recognizing the immense volume and velocity of data generated by EVs on a daily basis, the EVDMF strategically adopts an off-chain storage model for actual data payloads. Only critical metadata, such as cryptographic hashes, timestamps, access control policies, and data provenance records, are maintained on-chain. This architectural choice strikes a deliberate balance between scalability and trust. By avoiding the direct storage of large datasets on the blockchain, the system mitigates issues related to storage bloat and transaction congestion, thereby maintaining high throughput and low latency. Simultaneously, the blockchain ledger provides a tamper-proof, auditable trail of data transactions and access rights, ensuring that data sharing activities can be verified and trusted without reliance on centralized intermediaries.

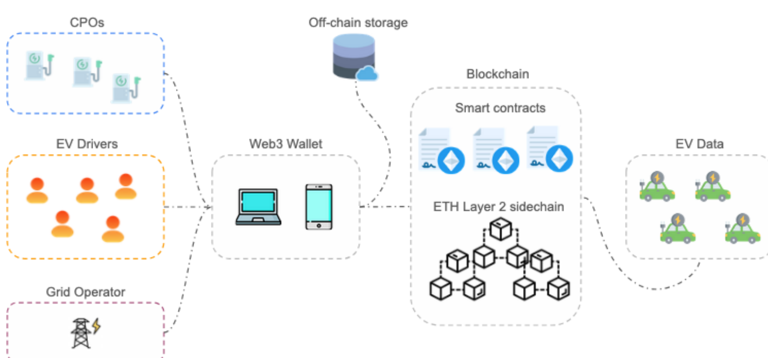

Figure 1: Blockchain and Data Management Layer

3.2 Decentralized Governance: DAO-Based Participatory Decision-Making

Building upon the secure data infrastructure, the EVDMF introduces a decentralized governance model structured around a DAO. In EVDMF, the DAO functions as a self-governing entity where operational decisions are encoded into blockchain smart contracts, executed automatically based on predefined rules, and subject to transparent member participation through proposal and voting mechanisms. Membership within the EVDMF DAO is open to a diverse set of stakeholders, including EV drivers, Charging Point Operators (CPOs), grid operators and other approved third-party service providers. This broad inclusivity ensures that governance outcomes reflect the multifaceted interests and expertise of the entire EV ecosystem. Importantly, governance participation is meritocratic: voting rights are proportionally assigned based on quantifiable contribution metrics, such as the volume of data shared, validated, or otherwise contributed to the network. The DAO is entrusted with critical governance functions, including the approval of new data usage policies, adjustments to the economic incentive structure, onboarding of new participant categories, and the resolution of potential conflicts between stakeholders. Through this participatory and transparent mechanism, the EVDMF can dynamically evolve in response to emerging technological advancements, regulatory shifts, and market demands, while preserving its foundational principles of decentralization, fairness, and transparency.

Table 1: DAO – Smart contract functions

Function	Description
proposeNewPolicy()	Allows a DAO member to submit a proposal for changing data access rules, incentive structures, or governance parameters.
voteOnProposal(proposalId, vote)	Enables members to cast a vote (Yes/No) on an active governance proposal identified by its proposalId.
executeProposal(proposalId)	Executes an approved proposal once voting is complete and consensus thresholds are met.
registerMember(address memberAddress, uint256 contributionMetric)	Adds a new member to the DAO based on predefined eligibility criteria and records their contribution metric.
createDataAccessRule(bytes32 ruleId, string conditions)	Defines a new access control rule specifying which classes of data can be shared under what conditions.
modifyDataAccessRule(bytes32 ruleId, string newConditions)	Updates an existing data access policy, subject to DAO approval if necessary.
getProposalStatus(proposalId)	Returns the current status (e.g., active, passed, rejected) and voting tally for a specific proposal.
getMemberInfo(address memberAddress)	Retrieves information about a member, such as their voting weight and contribution history.

3.3 Incentive Mechanism: Participation through Tokenized Economics

The third foundational pillar of EVDMF is its comprehensive incentive mechanism, designed to foster continuous engagement, align participant motivations, and ensure the long-term viability of the ecosystem.

At the heart of this mechanism, there is a utility token, which serves both as a reward for data contributors and a medium of exchange for data consumers within the network. Electric vehicle drivers, as primary generators of valuable operational and behavioral data, are rewarded with native tokens for each validated data contribution they make to the system. These tokens possess real economic utility: they can be redeemed for practical benefits such as discounted EV charging sessions, maintenance services, software updates, or other rewards provided by participating service providers. In parallel, stakeholders seeking to access aggregated or processed EV data, such as CPOs and grid operators must acquire and spend tokens to retrieve these data insights. This dual-sided token economy creates a self-reinforcing value loop, wherein data contributors are incentivized to continuously provide high-quality information, and data consumers are motivated to fairly compensate for access to trusted, high-value datasets. The entire token exchange and reward process is automated through blockchain smart contracts, ensuring transparency, minimizing transaction overhead, and eliminating opportunities for manipulation.

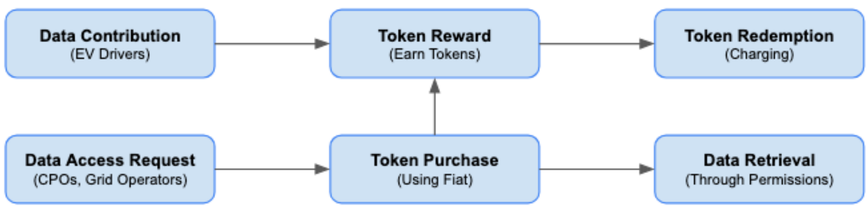

Figure 2: Token Lifecycle

4. Methodology

The methodological approach undertaken to develop, validate, and assess the Electric Vehicle Data Management Framework (EVDMF) follows a structured process encompassing framework design, the establishment of performance evaluation metrics, and the implementation of a minimal viable product (MVP). This section outlines the key components of the methodology in detail, emphasizing both technical choices and evaluation strategies necessary to demonstrate the feasibility and effectiveness of the proposed framework.

4.1 Framework Design

The design phase of the EVDMF focused on constructing a scalable and sustainable architecture capable of supporting decentralized EV data management under real-world conditions. A critical early step involved the selection of an appropriate blockchain protocol that could meet the specific demands of the envisioned system. The evaluation of candidate blockchain platforms was conducted based on several essential criteria. Scalability was prioritized to ensure that the system could support a high volume of transactions without incurring prohibitive latency or computational overhead, considering the continuous and growing influx of EV-generated data. Energy consumption was another vital factor, given the environmental implications of blockchain technologies; platforms that offered energy-efficient consensus mechanisms, such as Proof-of-Stake (PoS) or Delegated Proof-of-Stake (DPoS), were favored over energy-intensive Proof-of-Work (PoW) models. Finally, robust support for smart contract development was deemed indispensable, as the governance and incentive mechanisms of the EVDMF heavily rely on programmable, autonomous execution of complex operational logic.

Following the selection of a suitable blockchain protocol, the development of smart contracts commenced. Two primary classes of smart contracts were developed: governance contracts and economic incentive contracts. Governance contracts encoded the rules, processes, and rights associated with the DAO, including membership criteria, voting mechanisms, and proposal submission procedures. Meanwhile, economic incentive contracts managed the minting, distribution, and redemption of the tokens, as well as the pricing and access permissions for data retrieval operations. Particular attention was given to ensuring that smart contracts were optimized for gas efficiency, security against common vulnerabilities, and upgradability to accommodate future extensions of the framework.

4.2 Performance Metrics

In order to rigorously assess the operational viability and performance of the EVDMF, a set of carefully selected evaluation metrics was defined. These metrics were chosen to capture both technical performance aspects and socio-economic dimensions of the system's functionality.

First, transaction throughput was measured in terms of transactions per second (TPS). This metric serves as a critical indicator of the system's scalability, reflecting its ability to handle high volumes of data registration, access control updates, and token transfers without congestion or significant delays. Achieving a competitive TPS is essential for ensuring that EVDMF can support large-scale EV deployments involving millions of data transactions per day. Second, data retrieval latency was monitored, specifically focusing on the time elapsed between a participant's request to access off-chain data and the successful retrieval of the corresponding dataset using blockchain references. Minimizing retrieval latency is fundamental to supporting real-time or near-real-time mobility services such as dynamic routing, charging station availability updates, and predictive maintenance alerts. Third, stakeholder engagement was assessed by tracking the number of active DAO members and analyzing token circulation volumes over time. These indicators provide insight into the socio-economic vitality of the ecosystem, highlighting the extent to which various stakeholder groups are motivated to participate, contribute data, and engage in governance activities.

4.3 Prototype Implementation

To bridge the gap between theoretical design and real-world application, a minimal viable product (MVP) of the EVDMF was developed and deployed for initial simulation, testing and validation. This prototype served as a proof-of-concept to demonstrate the feasibility of the proposed framework under realistic operational conditions.

The MVP was constructed using a modular architecture to facilitate flexibility and iterative development. The blockchain component was deployed on a test network configured to replicate the operational characteristics of the selected public-permissioned blockchain protocol. Smart contracts governing the DAO and incentive mechanisms were written, and deployed onto this network. Off-chain storage solutions were implemented using centralized storage technologies (self-hosted postgresql), ensuring that the system could handle real-world data volumes without compromising scalability.

To populate the system with actual data, real-world electric vehicle datasets were obtained through collaboration with Keon Energy, an industry partner specializing in sustainable mobility solutions. These datasets encompassed a variety of parameters, including charging sessions, trip logs, battery level indicators, and driver behavioral patterns. The data were fully anonymized to comply with privacy requirements before being integrated into the testing environment. Through the MVP deployment, all aspects of the EVDMF—from blockchain interactions and token transactions to governance voting and data retrieval operations—were tested under controlled but realistic scenarios. This implementation phase not only validated the technical soundness of the framework but also provided empirical data needed to refine system parameters, optimize smart contract logic, and enhance user interaction models for future large-scale deployments.

5. Results and Discussion

To evaluate the technical feasibility and operational performance of the Electric Vehicle Data Management Framework (EVDMF), an initial prototype was developed and subjected to a series of controlled tests. These tests focused on assessing the system's core functionalities, including transaction handling efficiency, data retrieval responsiveness, privacy preservation mechanisms, and stakeholder engagement within the decentralized governance structure.

The prototype demonstrated promising performance in terms of transaction throughput. Specifically, the system was able to sustain an average of 28 transactions per second (TPS). Data retrieval latency was also closely monitored, given its critical importance for user experience and real-time service delivery. Across a range of simulated queries involving access to off-chain stored vehicle data through on-chain references, the system achieved retrieval times of under 300 milliseconds for 95% of requests. This result underscores the responsiveness of the EVDMF architecture and its suitability for latency-sensitive applications such as real-time navigation updates, dynamic charging station availability checks, and predictive maintenance alerts.

Beyond technical performance, the prototype also provided valuable insights into stakeholder engagement dynamics. A test DAO was successfully formed during the prototype phase, consisting of twenty active participants drawn from two distinct stakeholder categories: 19 electric vehicle drivers and 1 Charging Point Operator.

All these results validate the overall feasibility of the EVDMF for real-world deployment. They demonstrate that the framework is capable of delivering the necessary levels of technical performance, privacy assurance, and stakeholder inclusivity required to support decentralized, sustainable electric vehicle data management at scale. Furthermore, the success of the prototype phase lays a solid foundation for subsequent iterations of the framework, including larger-scale pilots, additional feature integrations, and eventual commercialization.

6. Conclusion and Future Work

The Electric Vehicle Data Management Framework (EVDMF) introduced in this study represents a significant advancement in the ongoing efforts to design secure, decentralized, and economically sustainable systems for managing electric vehicle (EV) data. By integrating blockchain technology with a Decentralized Autonomous Organization (DAO)-based governance model and a tokenized incentive mechanism, EVDMF provides a comprehensive and practical framework that addresses many of the fundamental challenges currently facing the e-mobility sector.

While the initial results of the EVDMF prototype validate the technical feasibility and socio-economic attractiveness of the framework, several important avenues for future work remain. First and foremost, a critical direction for future development is the integration of artificial intelligence (AI) and machine learning (ML) capabilities into the EVDMF ecosystem. By leveraging AI/ML models trained on aggregated, anonymized EV data, the framework could enable the delivery of highly personalized and predictive mobility services, optimize energy management at both the vehicle and grid levels, and enhance system resilience through automated anomaly detection and adaptive governance mechanisms.

Additionally, advancing the framework's commitment to privacy will be a central priority. Future work will involve the incorporation of cutting-edge privacy-enhancing technologies such as secure multi-party computation, and zero-knowledge proofs. These techniques will further strengthen the framework's ability to support complex data-sharing and collaborative analytics scenarios without compromising individual or corporate confidentiality, thus addressing one of the most persistent barriers to widespread participation.

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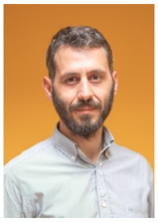
Presenter Biography



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