AvaDrive: A Blockchain Based Framework for Efficient Vehicle to Grid Management

Aurora Guaresi[1], Chiara Braghin[1] and Stelvio Cimato[1]

[1]Dipartimento di Informatica, Università degli Studi di Milano, Italy

Abstract

Electric vehicles (EVs) are widely recognized as one of the most effective solutions for reducing oil consumption and lowering gas emissions. Furthermore, EVs can be connected to the power grid for charging and/or discharging, leading to a great impact to our society for efficient management of electric grid infrastructure.

This paper investigates and discusses the potential integration of blockchain technology into vehicle-to-grid (V2G) systems to address some of the challenges associated to its large-scale adoption. Specifically, we examine the advantages and security improvements provided by using Avalanche, a blockchain platform, within the V2G context. We also introduce AvaDrive, a decentralized application (dApp) we have developed to facilitate efficient transaction management in V2G systems.

Keywords

Vehicle-to-grid, Avalanche, Smart Contract, dApp

1. Introduction

According to the latest report by the International Energy Agency's (IEA) on the global electric vehicle (EV) market, more than one over five cars sold are electric [1]. Moreover, the number is expected to continue raising, both compared to the last two years and over the last decade. In fact, despite the European automotive industry's crisis [2, 3], some brands such as BMW Group [4], Toyota Motor Europe [5], and Lucid Group [6] have registered an increment in hybrid (HEVs) and EVs sales. Furthermore, companies like Chevrolet [7], Jaguar [8], and Honda [9] have announced different initiatives in the EV sector. This trend is expected to expand also across emerging economies, including Vietnam, Thailand, India, Brazil, Indonesia, Malaysia, and Mexico. By 2030, it is estimated that 40,000,000 electric cars will be sold globally, without considering the global increase in lorries, buses, and two- to three-wheels EVs deals, further highlighting the overall transformation of the mobility sector.

Regarding the charging process, the report highlights that there are ten private charging points for each public one, and that the majority of users uses a domestic one. This trend significantly increases energy demand, placing additional strain on electric power systems. One potential solution is the integration of Distributed Energy Resources (DERs), such as solar panels, along with the development of resilient, coordinated infrastructures capable of data sharing to better respond to demand fluctuations. The IEA's manual [10] also encourages the adoption of bidirectional solutions to obtain stable levels of reliability and efficiency. Technologies like Vehicle-to-Grid (V2G), Vehicle-to-Building (V2B), and Vehicle-to-Home (V2H) make strategic use of EV batteries as energy storage systems that can supply power back to the grid, a building, or a home, respectively. These systems help support the electrical grid by mitigating demand spikes and aligning consumption with real-time energy generation. In this context, users transition into prosumers: individuals who both produce and consume energy.

The transportation sector is not new to the influence of prosumerism. The Sharing Economy (SE) and multiple car brands have supported this phenomenon, offering more and more car-sharing or shared mobility services instead of the vehicles themselves [11]. The Sharing Economy (SE), supported by various car manufacturers, has accelerated this shift by promoting car-sharing and shared mobility services in place of traditional vehicle ownership [11]. This evolution, coupled with the ongoing

DLT2025: 7th Distributed Ledger Technology Workshop, June, 12-14 2025 - Pizzo, Italy
aurora.guaresi@studenti.unimi.it (A. Guaresi); chiara.braghin@unimi.it (C. Braghin); stelvio.cimato@unimi.it (S. Cimato)
0000-0002-9756-4675 (C. Braghin); 0000-0003-1737-6218 (S. Cimato)

transformation of the energy industry, underscores the need for strong trust relationships among all stakeholders. At the same time, it highlights the importance of maintaining core security properties, such as those defined by the CIA Triad (i.e., confidentiality, integrity, and availability).

This paper aims to integrate blockchain technology into V2G, V2B, and V2H systems to address some of the major challenges hindering their large-scale adoption. Specifically, we explore the potential benefits, limitations, and security implications of applying Avalanche, a relatively new and underexplored blockchain platform, to the V2G domain. As a proof of concept, we developed AvaDrive, a decentralized application built on the Avalanche platform to facilitate energy sharing. The dApp provides users with realistic, context-aware estimates for energy transfer times, taking into account the specific characteristics and conditions of each vehicle. For the user interface (UI), we utilized the Angular framework [20], combined with the Taiga UI component library [21], Lucide icon set [22], and 3D models to enhance interactivity and usability. Authentication is handled through the integration of a third-party service, Web3Auth [23]. To simulate charging station behavior, we employed the "SAP – e-Mobility Charging Stations Simulator" [24], which communicates via WebSocket [25] and adheres to the Open Charge Point Protocol (OCPP) [26]. Our framework offers the following key features:

- *Decentralized Authentication & Privacy*: authentication is decentralized, and privacy-oriented, relying on a Web3-based third party service;
- *Efficient and Scalable Management of Energy Transactions*: our framework relies on Avalanche blockchain to achieve fast, low-latency, and energy-efficient transaction processing, ensuring scalability and strong security;
- *Development of Appealing GUI with good User eXperience*: the interface relies on advanced modules offering backward compatibility with Web2 application;
- *Simulation Environment for V2G*: our solution integrates a professional Charging Station (CS) emulator interacting with the developed dApp.

In particular, the final dApp is developed through the Avalanche blockchain platform, which adopts a peculiar consensus mechanism and network topology to support scalability. Thanks to these characteristics, the validation of transactions always takes around two seconds, guaranteeing efficiency, which is independent of the arranged gas price, and protection from typical cyberattacks.

The paper is organized as follows: Sect. 2 provides background on the key concepts underlying the proposed solution, with a focus on V2G systems and the Avalanche platform. Sect. 3 reviews related work in the field. Sect. 4 presents the proposed architecture, detailing its components and key features. Finally, Sect. 5 concludes the paper and outlines potential directions for future development of the dApp.

2. Background

2.1. Electric Vehicles recharging process

To optimise the HEVs and EVs charging process, it is important to understand its mode of operation. Inside a vehicle, we can have only three types of powertrain [27]. Then, we refer to an HEV when the vehicle integrates a bigger battery than traditional thermal engines (ICEV), recharged through regenerative braking, and which usually supports only low-speed driving. On the other hand, Plug-In Hybrids (PHEVs) can also be driven in a fully-electric mode like EVs (or BEVs). In short, we can have three grades of hybridisation based on how much the Internal Combustion Engine (ICE) is supported or completely replaced by the electric motor.

The recharging process can be performed through conductive charging, wireless charging, or over battery swapping. As the latter two technologies are still in their early phase of development [28], we are going to focus only on conductive V2G. In this context, three keys properties of the vehicle's battery must be considered: the capacity declared in kWh, and the maximum charge and discharge power declared in kW. Factors such as the material composition of the electric cell, its cooling system, which consumes electricity as well, the chosen charging mode and the CS itself all play an important role in the recharging time and the cell's life cycle. In practice, the full capacity of the battery is not always utilized efficiently.

From a security perspective [29], communication between the vehicle and the charging station (CS) presents several vulnerabilities that can be exploited by attackers. For example, an attacker could manipulate the system to receive more energy than paid for or, in bidirectional systems, falsely report having injected more energy into the grid than actually delivered. Cybercriminals may also intercept communication between hybrid or electric vehicles and the CS to extract sensitive information about the vehicle or its owner, or to disrupt the charging process entirely. For a detailed analysis of attack prediction and mitigation strategies targeting CSs, refer to [30].

To minimise the recharging time and prevent service disruptions, voltage fluctuations, and energy losses, the adoption of smart infrastructure is essential. Smart charging offers a more controlled and efficient alternative to unmanaged or delayed charging, helping to extend battery life and mitigate peak demand issues. Given the critical nature of these systems, it is crucial to apply rigorous risk analysis and management techniques, identifying vulnerabilities in the same way a cybercriminal might. One such vulnerability is the presence of a Single Point of Failure (SPoF) in centralized architectures, which can pose significant threats to both system reliability and data privacy. From the PUVEC (Urban Platform for Connected Electric Vehicles) project [31], we see that the communications are heterogeneous, and there is heavy traffic among the vehicles and the road infrastructure: an HEV or EV can be attacked by manipulating the information that they need to provide to the server, or they can be forced to not collaborate; an unauthorised node can also interfere to collect private data, and the network itself can be subjected to Denial of Service (DoS) attacks, for instance. A possible solution to obtain a more reliable and efficient system consists of integrating bidirectional charging through V2G [27]. In this way, the HEV or EV acts as an accumulator and can supply power to the electric grid when it does not recharge in Grid-to-Vehicle (G2V) mode. The vehicle can also provide energy to a single building in V2B, when other sources have peak requests and high prices, consequently. If these users were to use V2H at night and V2B at their workplace, we could have multiple advantages, such as obtaining a better Load Frequency Control (LFC) and "zero energy buildings" [32]. However, we should consider cells' degradation and their cooling systems as well as the charging times, establishing coordination between all the involved parties. There, the installation of DERs, particularly renewable ones like home solar panels, can be beneficial.

In the last few months, the American automaker Ford has partnered with Resideo, a smart home solutions company and Honeywell spin-off founded in 2018, on the "EV-Home Power Partnership" project [33] designed to explore the potential of electric vehicle batteries to support optimal home energy management. To illustrate the practical impact of this initiative, we can refer to home energy consumption data from the latest study conducted by Istat (Istituto Nazionale di Statistica) during 2020–2021. Due to the COVID-19 pandemic, energy use was elevated during this period, with the average Italian household consuming approximately 16 kWh per day [34]. Taking as an example the Ford F-150 Lightning, an all-electric version of Ford's iconic F-150 pickup truck equipped with Vehicle-to-Home (V2H) capabilities and a 131 kWh battery, we can estimate that the vehicle could power an average Italian household for up to eight days, aligning with Ford's own claims [35]. From a financial perspective, the base model of the F-150 Lightning pick-up costs around 60,000 Euros. In comparison, a typical home energy storage system is estimated to cost approximately 1,000 Euros per kWh of capacity [36]. Based on this metric, using the vehicle as an energy storage unit can result in significant savings, especially in terms of the initial investment.

The EU encourages the adoption of V2G in Regulation 2023/1804 [37] and in Directive 2024/1275, which plans the adoption of V2B [38]. However, for implementing V2G, V2B and V2H, we may need more complex infrastructures, as well as continuous and reliable communications [39]. Finally, the automotive sector has already taken some steps in the V2G, V2B and V2H direction. In fact, scholar buses have a huge decrease in the cost for each seat when they implement V2G [40]. Moreover, beyond the aforementioned Ford F-150 Lightning, several other automotive manufacturers have also embraced these technologies. Notable examples include initiatives by KIA [41], Nissan since 2016 [42, 43], the

Renault Group [44, 45], and Lucid's innovative RangeXchange system [46].

The mobility sector has been strongly influenced by the emergence of the SE [11]. This influence is evident in the shift among car manufacturers toward promoting the variable costs of car-sharing services over the fixed costs associated with vehicle ownership. Although the definition of the SE remains somewhat ambiguous, encompassing a range of consumption models, a comprehensive classification of sharing services within a unified framework is provided in [47]. These services also embody the concept of prosumerism, as previously discussed. In this context, establishing a strong foundation of trust among all participants is essential to ensure both security and privacy, particularly when handling sensitive personal data.

2.2. Blockchain applications

The blockchain is often associated with cryptocurrencies and the financial sector, but its applications can be extended to healthcare, logistics, and the energy industry too [48, 49]. Recognizing this broader potential, in 2018, an alliance of companies and associations including Continental, Marelli, SAE International, Stellantis, Honda, and General Motors established the Mobility Open Blockchain Initiative (MOBI) to promote the integration of Web3 solutions within the mobility sector [50].

Briefly, blockchain is a distributed database maintained across a decentralized network. It operates as a linear sequence of blocks, where each block contains a timestamp, transaction data, and the cryptographic hash of the previous block, ensuring data integrity and resistance to tampering. This structure inherently supports transparency, as all participants in the network have access to the same version of the ledger. In open and permissionless networks, where the number of participants is theoretically unlimited, consensus algorithms are essential for coordinating cooperation and defending against malicious actors. Distributed systems must solve the consensus problem, where each node must independently verify the validity of received information [51]. Common consensus mechanisms include Byzantine Fault Tolerance (BFT), Proof of Work (PoW), Proof of Stake (PoS), Proof of Authority (PoA), and the Stellar Consensus Protocol (SCP). Additionally, blockchain technology enables the execution of Smart Contracts (SCs) [52]. These are self-executing contracts with the terms of the agreement directly written into code. Once predefined conditions are met, the contract automatically executes without the need for a trusted intermediary.

Building on the previous discussion, we can now assess the key advantages and limitations of blockchain technology [49]. One of its primary strengths is decentralization, which eliminates the need for trusted intermediaries. Additionally, because data stored on the blockchain is publicly accessible and cannot be altered or deleted without consensus, it ensures integrity, transparency, traceability, immutability, and persistence. However, several challenges must also be considered. These include the high energy consumption of certain consensus mechanisms, the lack of interoperability due to software forking, and the risk of centralization if the number of active participants is too low. Moreover, blockchain adoption often requires a significant initial investment, and most platforms are still not sufficiently user-friendly for individuals without prior technical experience.

Cybersecurity and privacy are also critical in systems like transportation and energy. To address these concerns, blockchain implementations must incorporate robust cryptographic and privacy-preserving techniques [53, 54, 55]. Furthermore, thorough evaluations of each blockchain platform are necessary to mitigate common threats such as 51% attacks, double-spending [49], and the deployment of malicious smart contracts (Criminal Smart Contracts, or CSCs) [54, 56, 57, 58]. Formal verification of smart contract code is essential, and Machine Learning (ML) methods can be applied to monitor decentralized networks in real time for anomalous behavior.

Blockchain proves advantageous over traditional databases in scenarios where data immutability, lack of a central authority, and limited trust between parties are critical requirements [13]. As such, it is well-suited for sectors like the Internet of Things (IoT), Industrial IoT (IIoT), and Industry 5.0, particularly in energy and mobility applications. Major players in the oil and gas industry, such as Saudi Aramco, BP, Shell, Equinor, Chevron, Total, and Iberdrola, have already invested in blockchain-based energy trading platforms to improve transparency and traceability.

Blockchain also enhances the smart charging ecosystem by improving interactions between electric vehicles (EVs) and smart grids [59]. This integration of ICT with electric systems forms part of the Internet of Energy (IoE), a digitally coordinated network that includes smart grids, buildings, hybrid and electric vehicles, and distributed energy resources (DERs). IoE enables the creation of Virtual Power Plants (VPPs), which efficiently manage shared data and energy flow across prosumers and infrastructure components [60]. As the energy landscape shifts toward decentralization and renewable sources, where multiple parties can access the energy network without restriction, the existing infrastructure must continue to ensure both security and efficiency. In this context, HEVs and EVs become strategic assets, reducing the cost of installing and maintaining charging stations. Importantly, IoE allows us to augment, rather than replace, existing infrastructure with technologies that enhance efficiency, transparency, and security.

Blockchain can be beneficial to the IoE, optimising energy consumption through SCs, thanks to its properties of transparency and traceability. The most common platforms for energy trading applications are Ethereum and Hyperledger Fabric. Particularly, consortium or permissioned blockchains are often favored in energy contexts for their enhanced security models [19, 61, 62]. Avalanche is a layer-1, open-source blockchain platform compatible with the Ethereum Virtual Machine (EVM) [17]. Unlike Ethereum, Hyperledger Fabric, Polygon, IOTA, or Hedera, Avalanche was initially designed for the financial sector and employs a unique consensus mechanism focused on scalability and decentralization. This method belongs to the "Snow protocol family" [63, 17]: a subset of randomly chosen nodes must take the same decision on the validation of a transaction for a determined number of consecutive times. During each decision, the majority of nodes influences more and more the ones which did not agree initially, and transactions that generate conflicts are rejected. For example, we can have twenty nodes and assume that if fourteen out of these twenty confirm a transaction twenty consecutive times, we have reached the consensus. This penalises malicious nodes' behaviours while supporting efficiency and scalability because the number of validator nodes is independent of the network. Avalanche uses PoS, requiring 2000 AVAX tokens to operate as a validator on the Primary Network. In addition, it has a particular network topology. In the Avalanche Mainnet, we find a network of networks providing isolation, which supports efficiency and better work assignment for validator nodes. More in detail, the Primary Network contains three subnetworks: the Contract Chain (C-Chain), an EVM implementation to execute SCs, the Platform Chain (P-Chain), which manages validators and subnetworks, and the eXchange Chain (X-Chain), which is responsible for Avalanche Native Tokens' operations like AVAX. Moreover, the platform admits the creation of permissioned subnetworks.

While Avalanche is less widely adopted than some alternatives, its consensus mechanism and network topology make it a compelling choice for energy and mobility applications that demand scalability, resilience, and efficiency [58, 64, 65].

3. Related work

Building on the previous considerations, it is evident that P2P energy trading, V2G systems, and blockchain technology have the potential to reshape the mobility sector, especially the automotive industry. Blockchain can be leveraged not only for energy distribution but also for secure and transparent payment mechanisms, addressing several of the security concerns previously discussed.

There are numerous industrial initiatives exploring the integration of blockchain into energy and transportation infrastructures. Among the most notable is the Brooklyn Microgrid project, which combines P2P energy trading with blockchain [59, 66–71]. It is similar to the Swiss pilot project Quartierstrom. In these cases, citizens from Brooklyn and Walenstadt, respectively, could keep track of their energy consumption from a mobile dApp. Power Ledger is an award-winning software company that develops decentralised platforms to facilitate P2P solar energy trading [72]. For example, they have collaborated with Tata Power to support the relations between the Indian company and prosumers who also own CSs or batteries and accumulators. On the other hand, the Energy Web Foundation (EWF) uses Ethereum to help various energy companies towards the Web3 transition [73]. In 2018, Tokyo

Electric Power Company Holdings, Inc. (TEPCO) started investing in blockchain integration, including the P2P market Conjoule [74], and the EWF. The EU has also supported the P2P energy trading platform SunContract [75]. The latter involves more than 10,000 prosumers in Slovenia who can buy and sell renewable energy. Regarding Africa, the startup Lightency was founded in 2018 to facilitate energy trading among local communities. In this way, they can become more economically independent, and the electricity cost should decrease [76]. Moreover, in the US, there is the V2H project JuiceNet [77], in Germany, the Ethereum-based Share & Charge V2G dApp [78], and in Italy, the energy management platform PROSUME [79]. Despite these promising initiatives, many still lack a sufficiently large number of users to fully assess their security, reliability, performance, and scalability. Moreover, evaluating system interoperability, in particular communication between different blockchain platforms, remains a significant challenge [80].

Beyond the aforementioned use cases, various research institutions have proposed alternative solutions. For example, Chonbuk National University in South Korea has explored the use of Hyperledger Fabric for a P2P energy trading system, introducing a 'Parking Lot Local Controller' (PLLC) to dynamically switch between consumer and producer roles based on smart grid conditions [81]. In Italy, the University of Palermo, in collaboration with four industrial partners, has developed a blockchain-based platform designed for Energy Communities and bidirectional charging scenarios [82]."

So far, Avalanche has not been adopted for the design of P2P energy trading systems, and this motivates our choice for the development of the PoC. Let us remember that this blockchain is based on the EVM, but it uses a particular consensus mechanism to obtain more scalability and efficiency in the transactions' approval process. Moreover, even if it is less known, important companies such as Mastercard and KKR have collaborated with Avalanche [83].

Then, the PoC takes as a reference [19] and [18]. In detail, the first source proposes a Hyperledger Fabric-based system for validating users and paying for energy transactions. Moreover, it focuses on solving the oracle problem using a Certified Authority (CA) to guarantee the true identities of participants. The second article compares different blockchains to develop efficient SCs, which store data related to unidirectional EVs recharging. The group of Swiss researchers have chosen Ethereum to govern the energy transactions between hotels and their clients who own the vehicles. In fact, via a web interface, the hotels' managers can control the architecture in real-time while creating accounts for the clients who can oversee their HEVs and EVs charging process through a mobile application. There is a major focus on "transaction fees" and costs attributed to clients without using cryptocurrencies, while future developments are centred on scalability and the respect of privacy properties for data that is stored on-chain. In this particular paper, we can notice the use of specific data structures to memorise the information related to energy transactions. By the way, our contribution is characterised by peculiar elements, apart from the choice of Avalanche. In effect, we integrate a third-party service for users' decentralised authentication and remain in a simulation environment for the electric operations. In addition, we continue to consider V2G and bidirectional charging, distancing ourselves from the second reference. Finally, the project has been managed through an incremental process.

4. Under the Hood: AvaDrive's Architecture and Core Features

AvaDrive is a decentralized application developed as a proof of concept to explore the advantages, limitations, and security aspects of leveraging the Avalanche blockchain in the context of bidirectional charging, with a particular focus on storing data related to V2G energy transfers. The primary objective is to build a system that is secure, fully decentralized, and accessible, even to users with no prior experience in Web3 technologies.

The AvaDrive architecture is structured around three core components (Figure 1 illustrates the system architecture, including all integrated components):

1. *dApp*: this component manages user authentication and facilitates interaction with the blockchain via an *RPC endpoint*, ensuring seamless communication between the front end and the decentralized network.

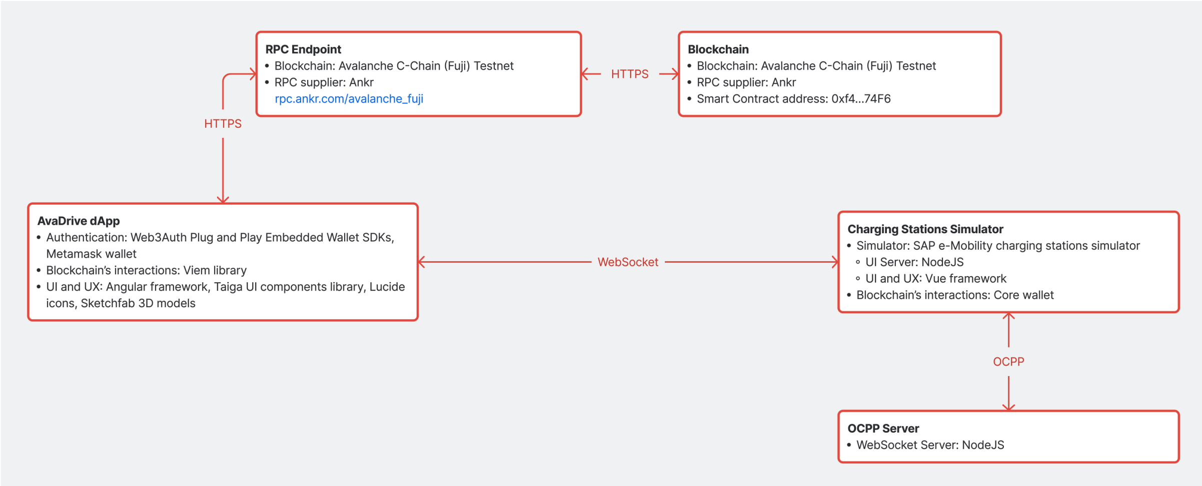

Figure 1: AvaDrive architecture including all the integrated components

2. *Blockchain layer*: this layer is responsible for securely recording energy transaction data and executing the smart contract that governs the logic of bidirectional charging operations.
3. *Charging Station simulator*: this component was designed to emulate real-world charging infrastructure. It includes an *OCPP server* running on the backend. The server acts as the central management system, handling transaction logging and communication with simulated charge points. Validated energy transactions can then be forwarded to the Avalanche blockchain for permanent, tamper-resistant storage.

The process flow is structured as follows: a user first authenticates, then he/she initiates an energy transaction — `input` if acting as a consumer, `output` if a producer, or `bidirectional` if a prosumer. Once the energy transfer is completed, the corresponding financial transaction takes place. The entire operation is then permanently recorded on the blockchain, ensuring transparency and immutability.

4.1. Components and their integrations

AvaDrive GUI. For the development of AvaDrive, we selected Angular [20] as the front-end framework due to its widespread adoption and maturity within the industry. The user interface (UI) and user experience (UX) are responsive and visually appealing, built using Taiga UI [21], a well-documented and actively maintained component library developed by Tinkoff Bank. To further enhance the interface, we integrated Lucide icons [22], 3D models sourced from Sketchfab [84], and layout inspiration drawn from Polestar's minimalist design approach [85].

Web3 has been defined as the new Internet era where the fundamental concept is "user-centrism", where individuals own their data and identities, supported by concepts like Self-Sovereign Identity (SSI) and privacy by design. This model leverages decentralization and interoperability, though it still faces key challenges such as Web2 compatibility, the absence of standardized protocols, energy-intensive scalability, and maintaining robust security properties [86, 87]. With these principles in mind, we evaluated several third-party authentication solutions and ultimately chose Web3Auth [23] as our authentication provider. Specifically, we implemented the "Plug and Play Web Modal SDK," which integrates smoothly with JavaScript-based frameworks like Angular and offers a user-friendly, out-of-the-box authentication experience without requiring extensive customization of the UI or UX.

Figure 2 presents three screenshots of the AvaDrive dApp: the homepage on a mobile device, the Web3Auth login modal from a laptop, and a sample energy transaction request as displayed on a vehicle's dashboard.

AvaDrive Smart Contract. We developed a smart contract to manage energy transfers for producers, consumers, and prosumers using Solidity within the Hardhat framework [89, 90]. Hardhat is a powerful

Figure 2: From left to right: AvaDrive homepage from a mobile device, authentication using Web3Auth from a laptop, and request of an energy transaction from a vehicle's dashboard.

development environment tailored for building, testing, and deploying smart contracts on Ethereum-compatible blockchains, including Ethereum itself, Avalanche's C-Chain, Polygon, and other networks that support the Ethereum Virtual Machine (EVM).

The smart contract distinguishes between: *public functions*, which can be called externally, *private functions*, which are restricted to internal contract logic, *view functions*, which read but do not modify state, and *pure functions*, which operate independently of state and storage. We also made use of Solidity's memory management: *storage* for persistent data tied to the contract's state, and memory for temporary data during function execution, and *calldata* for handling function inputs efficiently. These distinctions are crucial for optimizing gas costs and ensuring the contract remains lightweight and cost-effective.

To handle user roles, we implemented a structured mapping system that categorizes users into producers, consumers, and prosumers. Each energy transaction is associated with a unique hash, which helps prevent duplicate executions by the same user. We also implemented safeguards to verify correct contract execution, along with an internal function for cryptocurrency-based payments—tailored for our V2G simulation context. Figure 3 presents an excerpt of the Solidity code, showing: a *mapping* for user classification, a *public* function using memory to store prosumer data, and a *view* function to retrieve a user's charging history.

The smart contract was successfully deployed to the Avalanche C-Chain Fuji Testnet. To facilitate interactions with the blockchain, we integrated a third-party service for handling Remote Procedure Calls (RPCs). Based on the official Web3Auth documentation, we chose Ankr [88] as our RPC provider. The dApp communicates with the blockchain via Ankr RPC endpoints and the Viem library [91]. For testing purposes, we utilized two wallets funded with AVAX from the Fuji Testnet faucet. A MetaMask wallet is used by the dApp user, while a Core wallet serves as the transaction counterparty for each interaction.

Charging Station Simulator. To simulate the V2G environment, we integrated the "SAP e-Mobility Charging Stations Simulator" [24], which is part of the professional SAP e-Mobility platform [92]. This simulator operates using the OCPP-J protocol [26, 93]. To interface with it, we developed a Node.js server inspired by [94], supporting WebSocket communications [25]. Our dApp connects to the simulator's UI Server using the WebSocket API [95], and its JSON responses are parsed in order to be easily understood by the final user.

```
// contracts / AvaDriveSC.sol

mapping(address => Prosumer) public prosumers;

...

function addProsumer( Prosumer memory pros ) public {
        require(pros._erogationCapacity > 0, "Capacity must be greater than 0.");
        require(pros._erogationCapacity <= pros._batteryCapacity, "Cannot erogate
more than storage.");
        prosumers[msg.sender] = Prosumer({ _username: pros._username, _id: pros._id,
_userAddress: msg.sender, _place: pros._place, _available: pros._available, _soc:
pros._soc,
                _charger: pros._charger, _batteryCapacity: pros._batteryCapacity,
_erogationCapacity: pros._erogationCapacity, _EVmodel: pros._EVmodel,
                _balance: pros._balance });

        emit Registration (pros._id, pros._soc, pros._balance);
    }

...

function getChargingTransactions()  public view returns (ChargingTransaction[]
memory) {
        return chargingTransactions[msg.sender];
    }
```

Figure 3: Solidity code including mapping, a public function that uses memory to store prosumer's data, and a view function to obtain the user's charging history.

```
// src / app / sign-up / sign-up.component.ts

  try {
        const result = await walletClient.writeContract({
          address: AVADRIVE_CONTRACT_ADDRESS,
          abi: AVADRIVE_CONTRACT_ABI,
          functionName: 'addChargingTransaction',
          args: [otherUserCore, userMeta, sd, ed, 5],
          account: ACCOUNT_META,
          chain: avalancheFuji,
          gas: 60000n
        }).then((result) => {
          console.log("Energy transaction completed: " + result)
          this.dialogs.open(result, { label: 'Energy transaction completed',
appearance: 'cs_info', }).subscribe();
        });
      } catch (Error) { console.log(Error); }
```

Figure 4: TypeScript code to register an energy transaction on the blockchain with a gas fee equal to 60,000ns

In addition to the standard setup, our implementation includes a function that estimates energy transmission time whenever a transaction is requested. This estimation considers key parameters like battery capacity, max charge/discharge power, and the selected charging system, along with contextual variables such as weather conditions. The resulting (semi-randomized) duration is converted into milliseconds for simulation purposes. Once the simulated transfer completes, the energy transaction is recorded on the blockchain, and the corresponding payment is processed (Figure 4). Figure 5 illustrates a TypeScript code snippet that gets a casual element, estimates the charging duration, and handles the execution of the energy transaction.

4.2. Experimental Results

Despite the relative novelty of some of the technologies used, we successfully integrated them to develop AvaDrive, a decentralized application designed for producers, consumers, and prosumers within the V2G ecosystem. In particular, even if Web3Auth, Viem, Taiga UI, and Avalanche are not the most adopted in their respective sectors, they should be appreciated for their reliability. Avalanche's ecosystem is quite vast and accessible, and it easily cooperates with other systems because it is based on the EVM.

```
// src / app / sign-up / sign-up.component.ts

  getRandomIntInclusive = (min: number, max: number) => {
    const minCeiled = Math.ceil(min);
    const maxFloored = Math.floor(max);
    return Math.floor(Math.random() * (maxFloored - minCeiled + 1) + minCeiled);
  }

...

  energyTxStart = async () => {
    let randomErogation = 1;
    /* Values estimated from https://insideevs.com/features/707489/ev-charger-types-
levels/
       Assuming also max battery capacity = 100.
       Example all at min: 1 * (100 - 0) / 1.2 = 83.33 * 100 = 8333 = about 8 seconds
because 1000 = 1 second
       Example all at max: 100 * (100 - 0) / 350 = 28.57 * 100 = 2857 = about 2
seconds
    */
    // @ts-ignore
    if ( (this.userDataForm.get('charger')?.value).toString() === "L1") {
randomErogation = this.getRandomIntInclusive(1.2, 2.4); }
    // @ts-ignore
    else if ( (this.userDataForm.get('charger')?.value).toString() === "L2") {
randomErogation = this.getRandomIntInclusive(3.7, 22); }
    // @ts-ignore
    else if ( (this.userDataForm.get('charger')?.value).toString() === "L3"){
randomErogation = this.getRandomIntInclusive(50, 350); }
    const targetSoc = 100;
    // @ts-ignore
    let chargeTime = this.userDataForm.get('batteryCapacity')?.value * ( targetSoc -
this.userDataForm.get('soc')?.value ) / randomErogation;
    console.log(chargeTime);

    const socket = new WebSocket("ws://localhost:8080", "ui0.0.1"); // UI Server

    const myUuid = crypto.randomUUID();
    let payload: any[] = [myUuid, 'startAutomaticTransactionGenerator', '{}'];

    socket.onopen = () => {
      console.log("WebSocket connection established");
      socket.send(JSON.stringify(payload));
      socket.onmessage = (event) => {
        let sd = (new Date()).getTime();
        console.log(event.data + "Automatic transaction started at: " + sd);

        this.dialogs.open(chargeTime, { label: 'Energy transaction estimated time
(ms)', appearance: 'cs_info', }).subscribe();
        setTimeout( () => { this.energyTxStop(sd) }, chargeTime); // 2-8 seconds
      }
    }

    socket.onerror = (error) => { console.error("WebSocket error:", error); };
    socket.onclose = (event) => { console.log("WebSocket connection closed", event);
};

...
```

Figure 5: TypeScript code to get a casual element, estimate the charging time, and manage the energy transaction.

Moreover, it facilitates scalability thanks to its consensus mechanism and network of networks topology. This avoids congestion, so we can obtain transactions' confirmations in around two seconds as well as other benefits against common blockchain cyberattacks, such as the "double spending" one. On the other hand, a bad management of the subnetworks may undermine the blockchain's decentralisation.

Scalability and efficiency are crucial for V2G because we have a huge information traffic from different users. Security and privacy are important as well. Then, we can do some theoretical considerations using a system's DFMEA [96] and the data analysed in the OWASP Top 10 [97]. Focusing on high severity and RPNs values, we can delineate which failure modes are more dangerous than others and need more attention. In particular, we notice that high RPNs are especially due to their respective occurrence. We also did not prevent DoS attacks or the execution of CSCs. All of these aspects can become real security requirements in the redesign of some fundamental functionalities. Of course, we

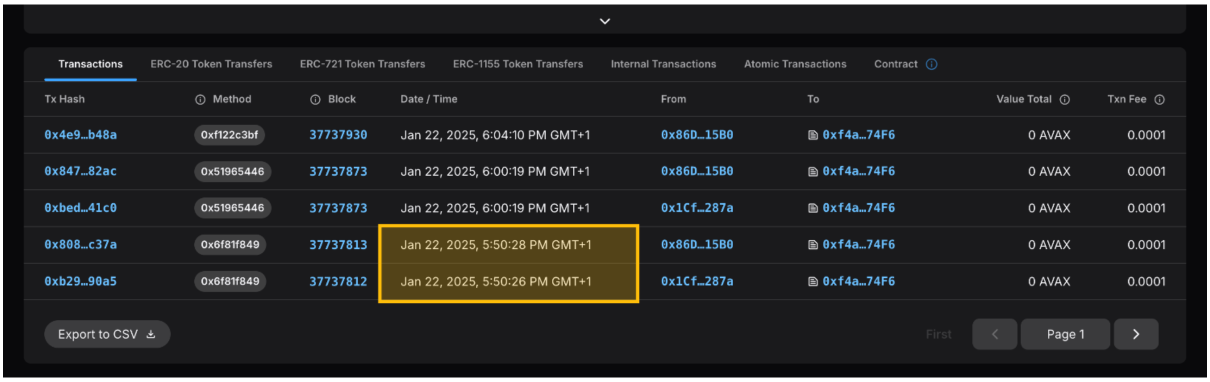

Figure 6: : Part of the transactions' ledger to verify performances

should also respect privacy [98]. Nevertheless, coming out of the simulation environment, given the whole real system architecture, we could apply other security analyses, such as the TARA [99].

As previously seen, we chose a fixed value for the "gas fee", equal to 60000 WEI or 0.00000000000006 ETH and, in January 2025, 0.0000000002 euros: a paltry cost that can be managed by producers and prosumers or included in the final user's expenses. From the public ledger, we can really observe that the cost for a single energy transmission contains 0.000000025 AVAX for the total "gas price". We decided to assign 0.000001 ETH for each kWh and we can see that an energy transaction costs from 0.00006000000006 to 0.00161232 AVAX. This means that the cost of energy is the most influential factor. We can also confirm that each transaction is validated in two seconds at maximum, independently of the paid fees. More in detail, we can take a look at the simultaneous automatic registration of two users to check this statement (see Figure 6).

In conclusion, we showed an efficient and secure dApp for the simulation environment, which also guarantees easy interactions with the blockchain for the final users, like a Web2 experience.

5. Conclusions and Future work

We started analysing the recharging process of HEVs and EVs to optimise it from a security perspective. We also briefly examined the economic context that is influencing the mobility sector, which can be correlated to the emergence of new P2P-based technologies. So, we analysed blockchain to guarantee fundamental security properties when diverse parties do not have a common bond of trust. Since this happens in IoT, V2G, and their variations, we can apply ICTs, including blockchain, to obtain the IoE. Therefore, data integrity, sharing, reliability, and scalability are essential to get resilience to failures as well as increase DERs adoption. In this context, HEVs and EVs are true assets. Then, we saw some business and research use cases, which applied blockchain to energy transfers and payments. After a comparison with other platforms, we have chosen two references to implement our Avalanche-based PoC. After, we described the advantages and disadvantages of the dApp AvaDrive for V2G energy transactions.

HEVs and EVs are modifying our day-to-day life and the current economy, V2G has the potential to act in an analogous way. Therefore, AvaDrive has been an opportunity to attest how blockchain, particularly the less-known platform Avalanche, can support the maintenance of essential security properties that optimise V2G.

In the future, we should redesign some functions that imply security, including cryptographic techniques and considering the storage of private data off-chain to comply with the right to be forgotten, imposed by the EU Regulation 2016/679 (GDPR) [100], for instance. Realising a physical infrastructure, we should also examine in-depth the interdependencies between the dApp and external systems to avoid DoS, the execution of CSCs, and eventually report temporary failures to users. Leaving the simulation environment, we can also integrate the "IDRO" mentioned in [38]. This would permit an easy identification of CSs from the dApp itself as well as prosumers' simple registration to the same register. From a practical point of view, a consumer or prosumer can benefit from the dApp directly in their vehicles or by scanning a QR code on the chosen CS. Moreover, we can integrate a payment method alternative to cryptocurrency, maybe offered by a third party. If we scale the architecture outside of the emulation field, we should exploit all of Avalanche's capacities, using multiple subnetworks, maybe distributed geographically, and letting them communicate through the Teleporter protocol, for example.

For all the mentioned reasons, AvaDrive can be a useful starting point to delve into the application of blockchain to V2G in our everyday life.

6. Acknowledgement

This work was supported in part by project SERICS (PE00000014) under the NRRP MUR program funded by the EU - NGEU. Views and opinions expressed are however those of the authors only and do not necessarily reflect those of the European Union or the Italian MUR. Neither the European Union nor the Italian MUR can be held responsible for them.

Declaration on Generative AI

The authors have not employed any Generative AI tools.

References

1 IEA, "Global EV Outlook 2024", Paris https://www.iea.org/reports/global-ev-outlook-2024, 2024.
2 The crisis facing the EU's automotive industry | Think Tank | Parlamento Europeo https://www.europarl.europa.eu/thinktank/it/document/EPRS_ATA(2024)762419
3 European carmakers brace for a deeper and longer downturn https://www.ft.com/content/7e0ca35e-d6a8-48b7-b657-cf547f3994cb
4 https://www.press.bmwgroup.com/global/article/detail/T0447427EN/bmw-group-maintains-bev-growth-path-inchallenging-market-situation-in-2024
5 https://newsroom.toyota.eu/multi-pathway-approach-to-co2-reduction-leads-to-all-time-sales-record-for-toyota-motor-europe-in-2024
6 https://lucidmotors.com/media-room/lucid-q3-2024-financial-results
7 https://news.reliant.com/press-releases/press-release-details/2024/Reliant-and-GM-Energy-Advance-Renewable-Energy-Mission-with-New-EV-Charging-Plan/default.aspx
8 https://media.jaguar.com/en-gb/news/2024/12/jaguar-unveils-type-00-unmistakable-unexpected-dramatic
9 https://global.honda/en/newsroom/news/2025/c250108aeng.html
10 IEA, "Grid Integration of Electric Vehicles", Paris https://www.iea.org/reports/grid-integration-of-electric-vehicles, 2022.
11 Mokter Hossain, "Sharing economy: A comprehensive literature review", International Journal of Hospitality Management, vol. 87, 2020.
12 https://documents1.worldbank.org/curated/en/177911513714062215/pdf/122140-WP-PUBLIC-Distributed-Ledger-Technology-and-Blockchain-Fintech-Notes.pdf
13 Mohammad Jabed Morshed Chowdhury, Alan Colman, Muhammad Ashad Kabir, Jun Han, and Paul Sarda, "Blockchain Versus Database: A Critical Analysis", 2018 17th IEEE International Conference On Trust, Security And Privacy In Computing And Communications / 12th IEEE International Conference On Big Data Science And Engineering (TrustCom /BigDataSE), New York, NY, USA, pp. 1348-1353, 2018.

14 Md Moniruzzaman, Abdulsalam Yassine, and Rachid Benlamri, “Blockchain and cooperative game theory for peer-to-peer energy trading in smart grids”, International Journal of Electrical Power & Energy Systems, vol. 151, 2023.
15 Serkan Seven, Yeliz Yoldas, Ahmet Soran, Gulay Yalcin Alkan, Jaesung Jung, Taha Selim Ustun, and Ahmet Onen, “Energy Trading on a Peer-to-Peer Basis between Virtual Power Plants Using Decentralized Finance Instruments”, Sustainability 14, no. 20: 13286, 2022.
16 Maria Zrikem, Inas Hasnaoui, and Rajaa Elassali, “Vehicle-to-Blockchain (V2B) Communication: Integrating Blockchain into V2X and IoT for Next-Generation Transportation Systems”, Electronics 12, no. 16: 3377, 2023.
17 https://build.avax.network/docs
18 Marina Dorokhova, Jérémie Vianin, Jean-Marie Alder, Christophe Ballif, Nicolas Wyrsch, and David Wannier, “A Blockchain-Supported Framework for Charging Management of Electric Vehicles”, Energies 14, no. 21: 7144, 2021.
19 Prince Waqas Khan, and Yung-Cheol Byun, “Blockchain-Based Peer-to-Peer Energy Trading and Charging Payment System for Electric Vehicles”, Sustainability 13, no. 14: 7962, 2021.
20 https://angular.dev
21 https://taiga-ui.dev
22 https://lucide.dev
23 https://web3auth.io
24 https://github.com/sap/e-mobility-charging-stations-simulator
25 Ian Fette and Alexey Melnikov, “The websocket protocol”, 2011.
26 https://openchargealliance.org/protocols/open-charge-point-protocol
27 Morsy Nour, José Pablo Chaves-Ávila, Gaber Magdy, and Álvaro Sánchez-Miralles, “Review of Positive and Negative Impacts of Electric Vehicles Charging on Electric Power Systems”, Energies 13, no. 18: 4675, 2020.
28 Trupti Dhanadhya, Swaraj Kadam, Shashikant Prasad, and Harshal Vaidya, “Advancements and Challenges in Electric Vehicle Battery Charging: A Comprehensive Review”, E3S Web of Conferences, vol. 601, 2025.
29 Alessandro Brighente, Mauro Conti, Denis Donadel, Radha Poovendran, Federico Turrin, and Jianying Zhou, “Electric Vehicles Security and Privacy: Challenges, Solutions, and Future Needs”, ArXiv abs/2301.04587, 2023.
30 Mansi Girdhar, Junho Hong, Hyojong Lee, and Tai-Jin Song, “Hidden Markov Models-Based Anomaly Correlations for the Cyber-Physical Security of EV Charging Stations”, IEEE Transactions on Smart Grid, vol. 13, no. 5, pp. 3903-3914, 2022.
31 Yosra Fraiji, Lamia Ben Azzouz, Wassim Trojet, and Leila Azouz Saidane, “Cyber security issues of Internet of electric vehicles”, 2018 IEEE Wireless Communications and Networking Conference (WCNC), Barcelona, Spain, pp. 1-6, 2018.
32 Yaolin Lin, Shengli Zhong, Wei Yang, Xiaoli Hao, and Chun-Qing Li, ”Towards zero-energy buildings in China: A systematic literature review”, Journal of Cleaner Production, vol. 276, 2020.
33 https://media.ford.com/content/fordmedia/fna/us/en/news/2023/12/07/ford-and-resideo-launch-ev-home-power-partnership-project-drivin.html
34 https://www.istat.it/informazioni-sulla-rilevazione/consumi-energetici
35 https://www.ford.com/trucks/f150/f150-lightning/2023/features/intelligent-backup-power
36 https://senec.com/it/blog/quanto-costa-un-accumulatore-di-energia-fotovoltaico-le-fasce-di-prezzo
37 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX
38 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX
39 Jan Lukas Demuth, Johannes Buberger, Annsophie Huber, Emma Behrens, Manuel Kuder, and Thomas Weyh, “Unveiling the power of data in bidirectional charging: A qualitative stakeholder approach exploring the potential and challenges of V2G”, Green Energy and Intelligent Transportation, vol. 3, Issue 6, 2024.

40 Lance Noel and Regina McCormack, “A cost benefit analysis of a V2G-capable electric school bus compared to a traditional diesel school bus”, Applied Energy, vol. 126, pp. 246-255, 2014.

41 https://www.press-eu.kia.com/d/RCR5enVsPVWn/latest-news#/2023/kia-outlines-smart-technologies-to-connect-and-charge-the-next-generation-of-sustainable-mobility-solutions:39609

42 https://global.nissannews.com/en/releases/nissan-to-create-electric-vehicle-ecosystem

43 https://global.nissannews.com/en/releases/nissan-to-launch-affordable-vehicle-to-grid-technology-in-2026

44 https://media.renaultgroup.com/vehicule-electrique-le-cea-et-renault-group-developpent-un-chargeur-embarque-bidirectionnel-a-tres-haut-rendement/?lang=fra

45 https://media.renaultgroup.com/renault-group-we-drive-solar-and-mywheels-join-forces-with-the-city-of-utrecht-to-launch-europes-first-v2g-enabled-car-sharing-service

46 https://lucidmotors.com/charging

47 Boyd Cohen and Pablo Muñoz, “Sharing cities and sustainable consumption and production: towards an integrated framework”, Journal of Cleaner Production, vol. 134, Part A, pp. 87-97, 2016.

48 Pinyaphat Tasatanattakool and Chian Techapanupreeda, “Blockchain: Challenges and applications”, 2018 International Conference on Information Networking (ICOIN), Chiang Mai, Thailand, pp. 473-475, 2018.

49 Julija Golosova and Andrejs Romanovs, “The Advantages and Disadvantages of the Blockchain Technology”, 2018 IEEE 6th Workshop on Advances in Information, Electronic and Electrical Engineering (AIEEE), Vilnius, Lithuania, pp. 1-6, 2018.

50 https://dlt.mobi

51 L. M. Bach, B. Mihaljevic, and M. Zagar, “Comparative analysis of blockchain consensus algorithms”, 2018 41st International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO), Opatija, Croatia, pp. 1545-1550, 2018.

52 Primavera De Filippi, Chris Wray, and Giovanni Sileno, “Smart contracts”, Internet Policy Review, 10(2), 2021.

53 Huaqun Guo and Xingjie Yu, “A survey on blockchain technology and its security”, Blockchain: Research and Applications, vol. 3, Issue 2, 2022.

54 Jorge Bernal Bernabe, Jose Luis Canovas, Jose L. Hernandez-Ramos, Rafael Torres Moreno, and Antonio Skarmeta, “Privacy-Preserving Solutions for Blockchain: Review and Challenges”, IEEE Access, vol. 7, pp. 164908-164940, 2019.

55 Weiqin Zou, David Lo, Pavneet Singh Kochhar, Xuan-Bach Dinh Le, Xin Xia, Yang Feng, Zhenyu Chen, and Baowen Xu, “Smart Contract Development: Challenges and Opportunities”, IEEE Transactions on Software Engineering, vol. 47, no. 10, pp. 2084-2106, 2021.

56 Xiaoqi Li, Peng Jiang, Ting Chen, Xiapu Luo, and Qiaoyan Wen, “A survey on the security of blockchain systems”, Future Generation Computer Systems, vol. 107, pp. 841-853, 2020.

57 Jing Liu and Zhentian Liu, “A Survey on Security Verification of Blockchain Smart Contracts”, IEEE Access, vol. 7, pp. 77894-77904, 2019.

58 Zibin Zheng, Shaoan Xie, Hong-Ning Dai, Weili Chen, Xiangping Chen, Jian Weng, and Muhammad Imran, “An overview on smart contracts: Challenges, advances and platforms”, Future Generation Computer Systems, vol. 105, pp. 475-491, 2020.

59 Yihao Guo, Zhiguo Wan, and Xiuzhen Cheng, “When blockchain meets smart grids: A comprehensive survey”, High-Confidence Computing, vol. 2, Issue 2, 2022.

60 Khizir Mahmud, Behram Khan, Jayashri Ravishankar, Abdollah Ahmadi, and Pierluigi Siano, “An internet of energy framework with distributed energy resources, prosumers and small-scale virtual power plants: An overview”, Renewable and Sustainable Energy Reviews, vol. 127, 2020.

61 Zhou Su, Yuntao Wang, Qichao Xu, Minrui Fei, Yu-Chu Tian, and Ning Zhang, “A Secure Charging Scheme for Electric Vehicles With Smart Communities in Energy Blockchain”, IEEE Internet of Things Journal, vol. 6, no. 3, pp. 4601-4613, 2019.

62 MyeongHyun Kim, KiSung Park, SungJin Yu, JoonYoung Lee, YoungHo Park, Sang-Woo Lee, and BoHeung Chung, “A Secure Charging System for Electric Vehicles Based on Blockchain”, Sensors 19, no. 13: 3028, 2019.

63 Team Rocket, Maofan Yin, Kevin Sekniqi, Robbert van Renesse, and Emin Gün Sire, “Scalable and probabilistic leaderless BFT consensus through metastability”, arXiv preprint arXiv:1906.08936, 2019.

64 Dejan Dolenc, Jan Turk, and Matevž Pustišek, “Distributed Ledger Technologies for IoT and Business Dapps”, 2020 International Conference on Broadband Communications for Next Generation Networks and Multimedia Applications (CoBCom), Graz, Austria, pp. 1-8, 2020.

65 Morsy Nour, José Pablo Chaves-Ávila, and Álvaro Sánchez-Miralles, “Review of Blockchain Potential Applications in the Electricity Sector and Challenges for Large Scale Adoption”, IEEE Access, vol. 10, pp. 47384-47418, 2022.

66 Qiang Wang and Min Su, “Integrating blockchain technology into the energy sector — from theory of blockchain to research and application of energy blockchain”, Computer Science Review, vol. 37, 2020.

67 Wenbing Zhao, Quan Qi, Jiong Zhou, and Xiong Luo, “Blockchain-Based Applications for Smart Grids: An Umbrella Review”, Energies 16, no. 17: 6147, 2023.

68 Nasser Al-Saif, Raja Wasim Ahmad, Khaled Salah, Ibrar Yaqoob, Raja Jayaraman, and Mohammed Omar, “Blockchain for Electric Vehicles Energy Trading: Requirements, Opportunities, and Challenges”, IEEE Access, vol. 9, pp. 156947-156961, 2021.

69 Morsy Nour, José Pablo Chaves-Ávila, and Álvaro Sánchez-Miralles, “Review of Blockchain Potential Applications in the Electricity Sector and Challenges for Large Scale Adoption”, IEEE Access, vol. 10, pp. 47384-47418, 2022.

70 https://www.brooklyn.energy

71 https://quartier-strom.ch/index.php/en/homepage

72 https://www.powerledger.io

73 https://www.energyweb.org

74 https://www.tepco.co.jp/en/press/corp-com/release/2017/1443967_10469.html

75 https://suncontract.org

76 https://lightency.io

77 https://juicenet.ai

78 https://shareandcharge.com

79 https://prosume.io

80 Shekh S. Uddin, Rahul Joysoyal, Subrata K. Sarker, S.M. Muyeen, Md. Firoj Ali, Md. Mehedi Hasan, Sarafat Hussain Abhi, Md. Robiul Islam, Md. Hafiz Ahamed, Md. Manirul Islam, Sajal K. Das, Md. Faisal R. Badal, Prangon Das, and Zinat Tasneem, “Next-generation blockchain enabled smart grid: Conceptual framework, key technologies and industry practices review”, Energy and AI, vol. 12, 2023.

81 Felipe Condon Silva, Mohamed A. Ahmed, José Manuel Martínez, and Young-Chon Kim, “Design and Implementation of a Blockchain-Based Energy Trading Platform for Electric Vehicles in Smart Campus Parking Lots”, Energies 12, no. 24: 4814, 2019.

82 https://www.blorin.energy

83 https://www.avax.network/enterprise

84 https://sketchfab.com

85 https://media.polestar.com/global/en/media/photos/list?searchTerm=app

86 Partha Pratim Ray, “Web3: A comprehensive review on background, technologies, applications, zero-trust architectures, challenges and future directions”, Internet of Things and Cyber-Physical Systems, vol. 3, pp. 213-248, 2023.

87 Weikang Liu, Bin Cao, and Mugen Peng, “Web3 Technologies: Challenges and Opportunities”, IEEE Network, vol. 38, no. 3, pp. 187-193, 2024.

88 https://www.ankr.com
89 https://hardhat.org
90 https://soliditylang.org
91 https://viem.sh
92 https://www.sap.com/products/scm/e-mobility.html
93 Binod Vaidya and Hussein T. Mouftah, “Deployment of Secure EV Charging System Using Open Charge Point Protocol”, 2018 14th International Wireless Communications & Mobile Computing Conference (IWCMC), Limassol, Cyprus, pp. 922-927, 2018.
94 https://github.com/mikuso/ocpp-rpc
95 https://developer.mozilla.org/en-US/docs/Web/API/WebSockets_API
96 IEC, “IEC 60812:2018 - Failure modes and effects analysis (FMEA and FMECA)”, Geneva, Switzerland, 2018.
97 https://owasp.org/Top10
98 Oluwafemi Akanfe, Diane Lawong, and H. Raghav Rao, “Blockchain technology and privacy regulation: Reviewing frictions and synthesizing opportunities”, International Journal of Information Management, vol. 76, 2024.
99 https://www.mitre.org/news-insights/publication/threat-assessment-and-remediation-analysis-tara
100 https://eur-lex.europa.eu/eli/reg/2016/679/oj/eng