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Certifying battery usage for V2G and second life with a blockchain-based framework

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ABSTRACT

This paper describes a blockchain-based approach for sharing data among all the actors involved in Vehicle-to-Grid programs. The shared information is used both for monitoring the health status of the vehicle's battery and for remuneration in Vehicle-to-Grid programs. A blockchain platform and a set of appropriate smart contracts have been developed for supporting the interactions among the different actors and for creating battery usage profiles. To protect sensitive data, we limit the visibility scope of such data only to subsets of actors using blockchain channels. This approach preserves the privacy of the car owner on one hand and guarantees the compliance to correct charging and discharging modes, on the other hand, by using dedicated smart contracts to manage data for each of the channels. The approach here described proposes and develops a blockchain-based ecosystem for efficiently managing electric vehicles especially when these are called to provide electrical grid services, such as it happens for Vehicle-to-Grid programs. In this case, it is indeed possible that the battery undergoes an accelerated aging and thus certified recording of charging data for legal liability is one of the issues here dealt with. When possible, data are collected from multiple sources (e.g. the charging station and the Electric Vehicle) and from different parties with conflicting interests for validating data and breaking data silos that are within the car, the charging stations and the Battery Management System.

1. Introduction

Vehicle-to-Grid (V2G) appears as a technology for providing cheap, flexible, and fast-responding distributed storage to grid operators through the use of electric vehicles' batteries. Similarly, V1G indicates the possibility to offer similar services but only under the charging mode, letting the battery discharge only during usage. Basically, the Electric Vehicle (EV) battery can provide "upward" or "downward" services thanks to the related power injection/consumption dispatch: in the first case (upward services), the battery will absorb more energy at the recharge point, in the second case, instead, (downward services) the storage system will absorb more power. Such services can be provided as fast frequency regulation services or as secondary or tertiary regulation for peak shaving and optimized re-dispatch of energy resources.

In the V2H, Vehicle-To-Home, system the EV provides balancing at local level, improving self sufficiency of homes equipped with a surplus of renewable energy production. Grid operators, based on the need to regulate the frequency and balance production and consumption, can send signals to the market operators, such as aggregators, which in turn can act on the available energy resources and in particular on EVs. To have an idea of the impact that EVs can have on the power system, it can be interesting to look at the 2020 International Energy Agency report [1]. The Agency estimates that with 250 million EVs on the road by 2030, considered in the sustainable development scenario, the contribution of EV recharge systems could reach up to 4%–10% of the average peak of evening demand in the main EVs markets (China, UE and USA), assuming no dispatch on charging systems. Besides, despite the apparent ease of use of such energy resource, its adoption for grid regulation puts several issues in terms of competing interests and infrastructure readiness. While to upgrade infrastructures, it is essentially a matter of political will and investments, the presence of different stakeholders with different interests puts a few issues about the handling of data collected from the vehicle and elaborated accordingly to transparently monitor the State of Health of the vehicle's battery. At the same time, as outlined in the literature above, there is

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a need of transparency also in transactions and certification of energy services delivery.

This paper provides the following contributions: (i) first, it defines a blockchain-based framework for tracing and tracking battery usage for V2G programs to permit second life applications; (ii) second, it defines how to use a blockchain-based distributed platform supporting multiple channels to partition data and logics into multiple visibility scopes for solving V2G issues; (iii) third, it validates the proposed framework with a real hardware and software experimental setup including a charging station supporting bidirectional energy flows and a dedicated EV in the Mediterranean island of Favignana as well as multiple smart contracts on the distributed tracking platform.

We propose to use the blockchain for handling data (and validation logic) in V2G applications and in more in general for second life use of EV batteries, because there are many actors with contrasting interests and they require transparency, traceability and trust. The EV manufacturer checks for the constraints of charging/discharging profiles and eventually invalidate the EV warranty; the EV owner wants to maximize the economic gain of second life programs while the EV driver (may not be the same person) wants to maximize the gain of V2G programs, even with insane charge/discharge cycles. Additionally, the insurance company fights against fake data of charge/discharge depth. The car owner wants to monitor the negative effects of (joint) high temperatures and high state of charge, which depend on the driver habits, but also wants to look over the negative effects that V2G programs may have on its own EV battery. Finally, second life battery users want to know how much the battery has been stressed during its first life.

2. Related work

Many authors have proposed the use of the Blockchain (BC) technology to achieve such transparency and security in the energy context. The BC technology has gained a huge popularity because of the wide variety of use cases where it can be used and the benefits it provides [2]. A confirmation of this popularity is provided by the 2020 'Deloitte global Blockchain survey', where blockchain technology appears solidly entrenched in the strategic thinking of organizations across industries, sectors and applications. In the energy sector, most applications are devoted to peer-to-peer energy trading [3,4], among end-users, these being either producers or prosumers [5], other applications concern electric vehicles [6,7]. Recent articles have presented very comprehensive investigations into energy blockchain and transactional energy [4,8], although few articles have considered in detail the application of blockchain technology to the provision of electrical load management services and even less to V2G and smart charging applications. In [9] energy flexibility services is considered an interesting application for the Ethereum blockchain technology, in this way, the adaptation of energy demand profiles is transparently visible to all the market actors (i.e.: Distribution and Transmission System Operators, retailers, aggregators). In [10] a secure framework for EVs charging supported by an energy blockchain system in Smart Communities is proposed. Its application for the implementation of transparent transactions, involving EV owners and the aggregator, is described and carried out. Different contract options are proposed for different types of energy sold to the user (green or non green energy). The decision process of EV owners in the presence of asymmetric information is also modeled. In this case, optimality of contracts allocation is attained through dynamic optimization. In [11], the authors concentrate on security of edge networks, such as Vehicular Energy Networks, and try to design an incentive-scheme based on permissioned blockchain for Renewable energy transmission, dispatch, and distribution, exploiting the movement of EVs across the city. Reputation is used as a metric for validators' trust. Finally, a pricing-based incentive mechanism that can optimally schedule the charging/discharging of EVs to optimize EVs' utilities while gaining the regional energy balance in Vehicular Energy Networks is presented. The authors of [12] highlight the idea of Internet of Vehicles. They propose a data trading framework exploiting a consortium blockchain where local aggregators audit and verify transactions records among data traders. Efficiency in data trading is guaranteed by a multi layer architecture, in which the edge layer provides functions of transactions among near vehicles and sends results to the blockchain layer for registration. The local P2P electricity trading model, proposed by the authors with Ethereum, provides a Vehicle-To-Vehicle trading system with optimized prices. In [13] the authors propose a solution to the increasing supply–demand mismatch between service providers and consumers caused by the uncoordinated use of electric vehicles. A blockchain platform for implementing Peer-to-Peer energy exchanges between electric vehicles and energy service providers for Demand–Response service management is presented. The proposed scheme achieves a balance between Demand–Response by providing incentives to EVs for their own interests, while ensuring privacy and data integrity without the need for third parties through the use of blockchain. Also the work in [14] proposes a Blockchain-based energy trading model for EVs, but to using Smart contracts to achieve Peer-to-Peer transactions between vehicles through a contrary auction mechanism. The results show that the proposed scheme achieves lower transaction execution times than traditional schemes. More recently, blockchain based platforms are proposed as supportive of V2G services still as local P2P markets, in which game theory is used to match demand and offer [15]. Other papers explicitly cite V2G services and propose the blockchain as a secure platform for trading bi-directional energy services to the network [16]. Reliable coordination of EVs charging and transparency in trading of energy for the EV market is also well addressed in other papers, such as [17–19].

Other important issues are privacy and security during energy exchanges among EVs or among EVs and charging stations. The possibility of identifying electric vehicles based on the current exchanged during the charging phase has been demonstrated. In fact, while the trading of resources takes place via secure communication protocols, the power exchanged during charging contains characteristics specific to each vehicle, as described in the work in [20]. To address these issues the authors in [21], propose a blockchain-based framework and a mutual authentication scheme for EVs and charging stations. A utility center is used to register the identities of both EVs and charging stations and to validate transactions created by charging stations before being sent to the blockchain. The utility center, after verifying the validity of the transactions sends its Merkle root hash to the blockchain, this way only the concerned user will be able to decrypt the transaction stored on the blockchain, ensuring both privacy and security on the network. While the authors in [22] propose a privacy-preserving decentralized fair exchange scheme that employs blockchain technology and smart contract to ensure participant privacy, identity privacy, amount privacy, and transaction unlinkability, enabling fair electricity/service exchange in V2G networks. In [23], the authors address the problem of vehicle privacy due to the recording of information and location of electric vehicles stored by charging stations. The authors propose a Matching Market-based solution to identify a charging station using reticular cryptography for secure communications. The presented l framework is efficient in terms of computational and communication cost, charging latency and load balancing index. In the paper in [24], an Internet of Energy (IoE) solution is considered to provide optimal charging and resource control in the electric vehicle era with power exchange and security. To overcome the IoE security problems inherited from the IoT, a Internet of Energy construction is again used for hierarchical cryptographic key generation. A Practical Byzantine Fault Tolerance (PBFT) is used as the consensus algorithm with the addition of an additional smart contract for the use of energy transfer, thus managing to ensure transparency, reliability, availability and fault recovery by inheriting aspects of blockchain. In [25] the authors propose a consortium blockchain to solve the privacy problem for bidirectional energy exchange between electric vehicles and the power grid and a heuristic algorithm that minimizes the total load deviation by optimizing the charging and discharging period of electric vehicles in order to reduce the negative effects induced by the disordered charging of electric vehicles on the power grid. The results show that the developed model can effectively mitigate load fluctuations while ensuring privacy among users.

As can be seen from the brief literature review above, most of the studies in the literature focus on the architecture of V2G networks, proposing a system able to optimally coordinate energy exchanges between vehicles or between vehicles and the electricity grid in order to optimize the economic benefits for the system stakeholders. Other studies instead focus on ensuring the privacy of users on the network While exchanging energy with the charging stations. In all the above papers, no consideration is given to battery usage and aging certification. V2G can help solve problems on electricity grids due mainly to renewable sources, but it is often ignored that participation in V2G services increases the number of charge and discharge cycles of EVs batteries. EVs, in addition to the normal charge and discharge cycles required for the drive, will be subject to additional cycles to give support to the grid. Li-ion batteries are one of the most promising solutions for storing the energy needed by EVs, but the energy and power performance of Li-ion batteries decreases over their lifetime especially when the number of charge and discharge cycles increases significantly over those expected by manufacturers [26,27]. This aspect, in addition to decreasing the useful life time of the batteries, resulting in an earlier replacement of the battery pack than expected by the manufacturer, could compromise the warranty of the batteries. In this paper, a permissioned blockchain-based platform, supported by Hyperledger Fabric, is proposed to offer V2G services and to implement on-line monitoring and certification of the State of Health (SOH) of the EVs batteries. The latter is important for a potential second use of the EVs' batteries. It is well known indeed that second life batteries are a promising and interesting area of application for stationary and grid use of EVs' batteries after disposal.

3. Actors, data and policies

In this section, the overall framework of Vehicle To Grid technology and its market integration in different countries is reported. The comprehensive review paper in [28] indicates that Electric Vehicles in V2G mode can provide different grid services: fast frequency response programs, capacity availability, energy self-sufficiency for homes (Vehicle To Home). The actors that are involved in these programs are Transmission and Distribution System Operators, aggregators and end users.

(R2.7) In an example scenario of a V2G program interacting with batteries second life market, the owner of an EV subscribes a contract with the Transmission or Distribution System Operator and is committed to deliver (but this is not the only service he can deliver) a primary regulation service when a frequency disturbance occurs in the power system. At the same time, he has a contract with the insurance company of the EV. For the primary regulation, the battery of the EV is used to inject or absorb a power surge through the recharge station, within milliseconds. We can hypothesize that for each intervention the EV owner is remunerated with a given amount. At the same time, the EV owner wants to be advised about the time and place in which his vehicle offers this service, as he wants to keep certified track of the aging of the battery of his vehicle. When given performance parameters of the EV battery decrease below a given limit, the owner is advised and the battery can be sold on the second life market and its features can be automatically certified. We can also imagine that the insurance company of the vehicle/battery wants to look over the usage of the EV to be sure that the aging is not related to a misusage of the vehicle/battery.

The climate change and the environmental crisis are two of the main drivers for developing renewable energy sources and the energy transition. Electrified mobility and its sub-systems, such as V2G systems,

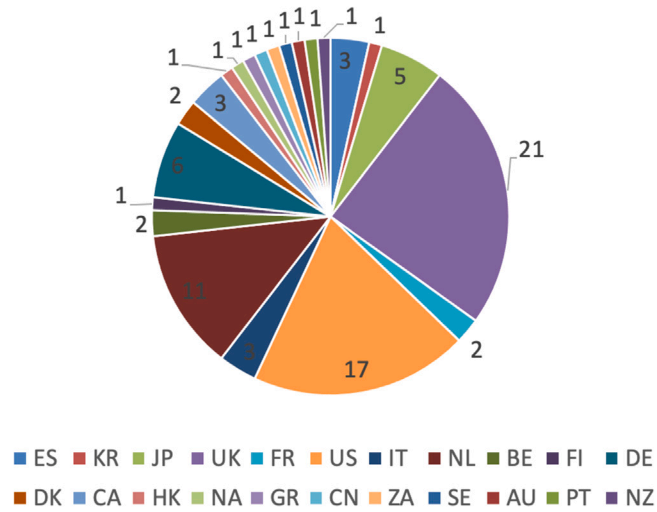

Fig. 1. Distribution of V2G projects per country.

have largely impacted both industry and civil society. Together with a growing number of papers on the topic, according to [29], there have been 85 projects on V2G in 22 countries since year 2009. Fig. 1 shows the number of V2G projects per country across the world, there is an increasing number of V2G projects in the recent years.

Out of the considered projects, about one third of them considers time shifting and charging schedules for shaving the peak demand and one fourth of them focus on frequency response. While the reserve, arbitrage, distribution services and emergency backup are less frequently considered. UK and US are the two top countries in the world in terms of number of experimental activities with 21 and 17 projects respectively. Among vehicle manufacturers taking part to V2G projects, Renault, Nissan and Mitsubishi have the largest share (60 percent) of these projects. Even with all tangible benefits, V2G remains a niche product, as it has not experienced a wide uptake, even in areas with deep electric mobility adoption. There are a number of motivations for this, ranging from economic, financial and customer experience. The most important ones seem to be stemming from the sector coupling itself and from the difficult relation between insurance companies, car manufacturers, grid operators and end users. The first motivation can be cleared out observing that automotive and electricity have developed as two separate systems. Each sector has rules, technical norms, practices, relationships, different user needs and infrastructure that must change to set the basis for shared and intersecting service deployment around V2G. The second motivation resides in the still unclear effects of V2G services on batteries aging and in the difficulty in separating the aging mechanism due to misuse from car owner and to V2G grid service offering.

3.1. V2G projects and programs across Italy

In Italy, three projects are currently running. The first [30] involves 700 Fiat Chrisler EVs and seems to be the largest EV parking lot in V2G mode in the world. It is located in Turin. The second is the BLORIN project [31], led by the University of Palermo and carried out by the authors together with Exalto Energia, Regalgrid Europe and the two grid operators of two Mediterranean islands. The project aims at the development of a blockchain platform for managing different energy resources including one V2G charger. This paper describes some experimental activities of the BLORIN project. The third project [32] is headed by Enel-X since 2017 and involves 2 chargers. Initially deployed as unidirectional systems, they can easily be turned into bidirectional chargers, while still awaiting the definition of the regulatory framework for V2G in Italy. As far as institutional programs are concerned, the company RSE (Ricerca di Sistema Elettrico) owned by GSE (the Italian public Grid manager) has recently carried simulations about the impact of EV recharging in two different case studies: home charging and fleets charging [33]. One of the aims of this research was to evaluate the positive impact on the users' electricity bill related to the performance of balancing services carried out by EVs during their charging phase. The study analyzes also the possible economic revenues, for the end user, from the participation to network balancing services. The energy exchanged is associated with costs and revenues which are therefore included in the users' electricity bill. RSE assumes that exchanges of energy for recharging are carried out, as far as possible, as a balancing service, downwards and/or upwards. To this end, the EVs' participation in the Dispatching Service Market (MSD) is simulated, more precisely in its real-time phase, i.e. the Balancing Market (MB). The four conditions of: V1G with and without dispatch, V2G with and without dispatch are then analyzed. Whenever the bid price for upward/downward service on the MB is higher than the minimum value of similar bids in the same market, historically, the authors assume that the offer is accepted by the TSO (Terna). In correspondence with the acceptance of an offer, it is assumed that a dispatching order, for which the vehicle is required to accordingly modify the power exchanged with the grid, is issued. When approaching the end of the charging period, if the battery State Of Charge (SOC) has not reached the desired level and there is not enough time to reach it, following the offer on the balancing market, the EV is charged to the desired SOC value at prices of the Day Ahead Market (DAM). To carry out the calculations, RSE considered the average, hour by hour, of the historical prices of the balancing service offers, upwards and downwards separately, accepted on the MB, in the Northern area of the country over a whole year. The algorithm only takes into account the costs of electrical energy, in terms of market prices (on the MB or DAM) thus excluding system charges, taxes, duties and VAT. On the basis of these assumptions, the most favorable case was the V1G, setting the recharge between 6 p.m. and 9 p.m. which allows a reduction in recharge costs of 37%. According to the simulations made by RSE, the user could recover from 20%–30% up to 60%–70% of the costs to recharge the vehicle, based on the selected scenario among the four considered. However, a certain acceleration of battery aging must be taken into account, due to the greater and more frequent power flows through the batteries. The new Decree of the Ministry of Economic Development, issued in February 2020, allows the inclusion of the V2G model in the Virtual Unit of Mixed Aggregation (UVAM), as planned in the pilot projects carried out by the TSO across Italy [34]. UVAMs allow users to provide flexibility by modulating consumption or production through for example Demand–Response programs [35] or V2G. Managed by Balancing Service Providers (BSPs), UVAMs offer capacity to the ancillary services market and are remunerated on the basis of the variation of the exchanged energy derived on the ancillary services market (€/MWh) plus a fixed amount (in €/MW/year) proportional to the aggregate offered capacity, and awarded by auction. In such Aggregation, all the energy resources operate as if they were a single virtual electricity production/consumption/storage system when participating in the provision of balancing and regulation services. The Decree provides for the possibility of reducing the minimum size for UVAMs consisting exclusively of EVs charging points from 1 MW to 200 kW. In addition, an incentive is provided to cover the additional costs associated with the installation in the charging points of the technologies aimed at ensuring the interaction between the EV and the network. Finally, the decree provides for simplified procedures for participating in UVAM for some categories of charging stations (such as domestic ones) and, above all, opens up the possibility of providing new types of services, such as frequency and voltage control. The decree introduces the notion of UVAR, "Virtual Units Enabled for Recharging", consisting exclusively of refueling points for zero-emission cars.

3.2. Monitoring the State of Health of EV batteries

The estimation of the State Of Health, SOH, of EVs batteries is one of the main problems related to their second life usage. According to the standard ANSI/CAN/UL 1974 (Evaluation for Repurposing Batteries), the assessment of minimum battery features to be employed for the second life must follow some laboratory tests. However, only few papers in the literature suggest that such evaluation can be done during the EV's usage, and the complicated aging mechanism of the battery makes the task harder. What appears evident from all papers on the topic is that aging is connected to the relation between battery's external voltage and SOC. As the time goes by, the maximum voltage is achieved at decreasing SOC values. The distance between these two points is a parameter related to aging, which decreases as aging proceeds. In [36], an interesting method for battery SOH estimation uses the location interval between the two inflection points or the transformation parameter of the differential voltage ($\Delta V - \Delta SOC$) curve. Another paper [37] uses a neural network that can be trained along the initial 400 cycles of charge and discharge. In this paper, the temperature, external battery voltage and SOC are registered on the blockchain every day to assess the progression of the aging state of the battery and to relate such progression to the EV's usage. All papers, however, lead to similar conclusions about the negative effects of usage habits (cycling and calendar aging) and environmental conditions. For this reason, in this paper, based on these empirical rules, the authors propose an on-line system for the monitoring of the aging of the battery. As referenced in [38], the factors affecting the aging of batteries are: the intensity of the charge/discharge current, the temperature, and the Depth of Discharge (DoD). Based on this, aging models that summarize the fundamental aspects have been created. The temperature is a parameter that influences a lot the degradation of the batteries and is used to implement accelerated life-time tests. The fundamental law by which the degradation occurs is summarized in the Arrhenius law as a function of time. The work in [39] reports a mixed aging protocol combining cycling and calendar repetitive phases. Experimental tests carried out on a Lithium Ion battery are presented and discussed against conventional accelerated cycling tests at the same conditions. Under calendar tests, the EV is parked with given SoC and at given environmental temperature. This is the case of EVs that stay parked for almost all day (90 percent of time). Tests have been carried out considering fixed SoC and temperature and then variable SoC and fixed temperature and then variable SoC and temperature. At fixed SOC and temperature, the largest capacity fade (from 12% to 30% for different Li-ion technologies) was experienced for calendar test at 60 °C and after 200 days at SOC 80%. Moreover, the higher the ambient temperature, the larger the capacity fade. Other experiments were carried out with fixed SOC and variable temperature. The temperature ranges considered were from 0 °C to 30 °C and from 30 °C and 60 °C at different SOC levels. It was again proved that worst performances in terms of speed of capacity fade were observed for the range 30 °C–60 °C regardless the value of SOC. Other tests were carried out at given temperature and with variable SOC. The test carried out at 45 °C was alternating weeks with 30% SOC with weeks at 80% SOC. It turned out that for the different analyzed technologies, the capacity fade was stronger if the SOC was at 80%. As a result of all these empirical tests, the best results in terms of aging and capacity fade can be attained keeping the car parked at 15 °C–20 °C and with a SOC between 20% and 40% [40].

4. Framework and architecture

This paper presents the BLORIN blockchain-based V2G platform for collecting, elaborating, and sharing data with different actors involved in the grid services for Electric Vehicles, as shown in Fig. 2. Data are taken from mainly two sources: the EV through an On-Board Diagnostics (OBD) device and the Charging Station (CS), then, data are

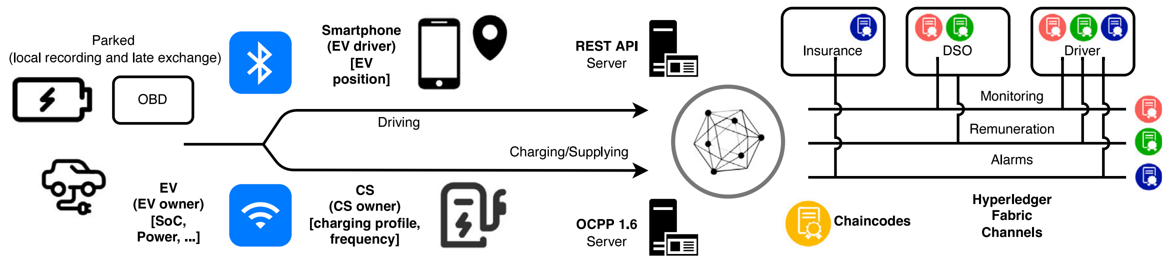

Fig. 2. Structure of the proposed architecture. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

sent to the different channels of the blockchain platform. The possibility to grab data from different sources owned by different actors with contrasting interests (i.e.: car owner and EV recharger company) is a further element for validating data. Data are collected and transferred to the blockchain with different methodologies, depending on the usage of the EV. In case the EV is moving, data are collected through the OBD and stored in the driver's smartphone, using Bluetooth, then through the cellular connection it pushes data to a REST API server. When the EV is connected to a charging station, the charging station provides the *meterValues* data through OCPP 1.6 protocol. Our platform relies on Hyperledger Fabric, a platform designed for use in business contexts, with a highly modular and configurable architecture that enables innovation and versatility for a wide range of use cases in the industry. We chose a permissioned platform for this application because permissionless blockchains provide greater security in case data can be released publicly but, due to privacy and the computation time of the heavier consensus algorithms, may not be adequate for all applications. Fabric, unlike the most famous Ethereum, supports SCs written in generic programming languages like Java, Go and Node.js. The SCs are called "chaincodes" and they work as a reliable distributed application that acquires its security/trust from the blockchain and the underlying consensus among the peers. In an Hyperledger Fabric network, the SC represents the main element of the network, because it is the component that implements the logic of each kind of transaction and verifies the integrity of each transaction sent by network users. The chaincodes are tools that allow the users to interact with the blockchain ledger, in fact, any operation, even a simple query, is performed in Fabric through the SC. The SCs are installed on each peer, and every time a user sends a transaction proposal on the network, this transaction proposal is processed by the SCs of all peers. Then, if the transaction sent by the user is consistent with the logic implemented by the SC and verified by all peers, the new transaction after the consensus process is recorded in a new blockchain block. Regarding privacy within the blockchain network, Hyperledger Fabric supports partitioning the blockchain into many components, named "channels". Channels allow for data isolation and confidentiality and by which the peers can communicate with each other. On a specific channel, the ledger is shared across the peers taking part in that channel, and transacting parties must be properly authenticated to a channel in order to interact with it. Hyperledger Fabric offers the possibility of creating different channels on the same network, allowing a group of participants to create a separate transaction ledger. If two participants form a channel, these two participants, and no one else, have copies of the ledger for that channel preserving the privacy and confidentiality of both.

For our purposes, as shown in Fig. 2, we use 3 channels for *(i) monitoring; (ii) V2G; and (iii) alarms.* A specific smart contract which aims at implementing the logic of transactions, and thus services, was developed and deployed on each channel. Data are accessible to different parties according to their role in the platform and the corresponding capability to subscribe one of the above-mentioned channels.

For example, the insurance company can only access *Alarms* channel, but cannot access data on the *Monitoring* and *Remuneration* channels. Conversely, the grid operator (DSO) or the provider of electric services can access the *Monitoring* and the *Remuneration* channels. Unlike many other blockchain platforms, in Fabric, chaincodes can invoke other chaincodes. This is true also among chaincodes that live on different channels, as an example, in Fig. 2 chaincodes residing in different channels are identified with different colors. In this case, one peer may participate in more channels and can run other chaincodes on other channels.

Table 1
Data visibility for stakeholders based on channel subscription.

Stakeholder	Monitoring	Remuneration	Alarms
EV owner	×	×	×
EV manufacturer	×		×
EV driver	×	×	×
Insurance company			×
Charging station	×		
DSO	×	×	
TSO	×	×	
Battery owner	×		×
Aggregator	×	×	

Table 2
Assignment of data types to channels.

Data type	Monitoring	Remuneration	Alarms
Charging baseline		×	
Istantaneous power	×	×	×
Connection status	×	×	×
Temperature	×		×
Charging profile	×	×	
Charging current	×	×	×
Battery SoH	×		×
Battery SoC	×		×
Cell battery voltage	×		×

The visibility of data toward the different V2G actors is explained by the mean of Tables 1 and 2. The first table shows which stakeholders can subscribe a specific channel, the second table shows which data are written on such a channel. The first table can be used also to understand the relations between stakeholders. As an example, the Insurance company has an 'x' in Alarms and therefore it reads some data types with all the stakeholders that hold a 'x' in Alarms channel (e.g. the EV owner). However, this fact does not guarantee that the EV owner and the Insurance company can access the same types of data, as they can be linked to different sets of channels. The stakeholders list depends of course on the business model underlying the scenario. It is indeed possible that the battery is owned by a third party which is different from the car manufacturer and this third party could be interested in the second life market.

The three channels are used for monitoring, remunerating, and warning for V2G services. By means of blockchain, certification and tracking of data is underlying the three functions. In particular, the alarm channel is used to monitor possible misuses of the Electric vehicle that may affect the battery SOH. On the monitoring channel data are provided continuously, at almost regular intervals. On the other channels, the blockchain transactions are written asynchronously, only when V2G events that meet specific requirements occur or the owner performs actions that affect the EV battery SOH. Differently from standard environments, in the proposed platform, a distributed data validation is needed. Before starting collecting data both from the EV side (OBD channel) and from the recharging station, before recharging, mutual authentication between these two entities is required. Even the battery has to be uniquely identified. These data are then connected to the user ID for billing/incentive recognition purposes. However, authentication details are not addressed in this paper and we consider both legacy authentication mechanisms and the recent advances as in [21]. Our focus is on the traceability of relations between batteries, vehicles and users, three uniquely identified items whose relations may change over time. In fact, the second life of EV batteries is indeed possible and, in this case, ownership should be disconnected both from the EV and from the battery itself.

The battery aging is a slow phenomenon (order of days) that does not require high sampling rate. This consideration, permitted us to find the best tradeoff between data freshness (the time between the production of the data and the timestamp of when it is written on the blockchain) and scalability (how many EVs can be served in parallel by the proposed framework). In our experimental setup the EV accumulated several data from more events but fires only one digest transaction every couple of days. Unfortunately, on the island of Favignana there are no many EVs and no more than one bidirectional charging station, therefore a scalability analysis can be done considering data available on the literature and from our previous experiments, which state that Hyperledger Fabric can sustain at least 300 transactions per seconds. Therefore, if each EV fires a transaction every two days we obtain the following result, which fits the needs of a country like Italy (forty millions of vehicles), in the case all of them would be EVs, such as it is planned in EU by 2035. The maximum number of EVs that can be handled by this technology can be computed as follows.

$$300\frac{[tx]}{[s]}\times 24\times 60\times 60\frac{[s]}{[day]}\times 2\frac{[day][EV]}{[tx]}\approx 52\cdot 10^{6}[EV] \tag{1}$$

5. Security analysis

5.1. Attack model

Our attack model takes into account the interest of the parties to manipulate data. Therefore, our solution has to provide (mutual) authentication among the parties and accountability for each chunk of information written on the blockchain. The participating actors may be tempted to misbehave for several purposes, mainly due to the economic advantage they can obtain. However, we assume that the economic advantage is lower than the disreputing and the consequent penalties if the misbehavior is publicly revealed. Therefore, for the security analysis of the proposed architecture, we refer to the mutual authentication among the parties, distinguishing the two cases reported in Fig. 2: the EV is in driving mode, or it is charging/supplying, respectively represented in the upper and lower parts of the figure. Consider one *domain of trust* the group of devices that are operated by the same person or by many people sharing the same interests; in such a case, the driving mode differs from the charging one also for the attack model and the domain of trust.

5.2. Mutual authentication in driving mode

Fig. 3 refers to the *driving mode*, the upper path in Fig. 2. In such a case, the EV, the smartphone, and the API endpoint constitute a single domain of trust as they all have the same interest; the second domain is the blockchain node, depending on the blockchain channel where the data has to be written. Therefore, as for trust, there are only two groups of entities: the ones representing the ith user (indicated by $EV_i/smartphone_i/API_i$), the second representing the blockchain peer $Peer_j$, being the trust among the different peers in the blockchain is handled by the blockchain itself. We recall some basic definitions and one theorem from [41], applied to the current case; analogous apply to Section 5.3.

Definition 5.1. A Message Authentication Code, MAC is said to be unconditionally (ϵ, Q)-secure if the adversary cannot construct a valid tag for any new message with probability greater than ϵ, given that the adversary has previously seen valid tags for at most Q messages. The fixed key k is not known to the adversary and is used to construct all the Q tags.

Definition 5.2. An authentication scheme is defined to be unconditionally (ϵ, Q)-secure if the adversary cannot bring the true authenticating entities to accept an authentication, where the adversary is an active participant, with a probability greater than ϵ, given that the adversary has previously seen Q previous authentication sessions between the parties.

Theorem 5.1. *We consider that MAC is an (ϵ, Q)-secure message authentication code and that the random challenges r_m is a n-bit random number, then the protocol reported in Fig. 3 is a $(Q/2^n + 2\epsilon, Q/2)$-secure mutual identification scheme.*

5.3. Mutual authentication in charging/supplying mode

Fig. 4 reports the protocol under the case of multi-actor authentication; in fact, in the charging/supplying mode, the EV, the CS and the OCPP server are operated by different entities (please, see the bottom path in Fig. 2). We purposely simplify the scenario in Fig. 4 by considering only the charging station CS_h, neglecting the OCPP server. We also graphically simplify the protocol description removing all the details that are analogous to those reported in Fig. 3.

It worth noting that, unlike the case shown in Fig. 3, in Fig. 4 the authenticating subjects use two different pre-shared keys, $k_{h,j}$ and $k_{i,h}$, to avoid *intruder-in-the-middle attacks* where an attacker can create two *matching conversations* [41].

6. Experimental setup

To gather data from the EV during the phases of injection and withdrawal of power in and from the network, it is possible to query the charging station. However, as indicated above, it is important to get data also when the vehicle is not connected to the charging station (e.g. for monitoring the battery status, the dept of charge, the temperature, the usage profile). Therefore, to get data from the EV in every condition, we deployed an OBD device on the vehicle. OBD were initially designed for control and diagnostic functions under the US Environmental Protection Agency, EPA, and emission standards. Over the years, OBD devices have become more sophisticated. OBDII, a new standard introduced in the mid-1990s, provides almost complete control of the engine and also monitors parts of the chassis, body and accessory devices, as well as the car's diagnostic control network [42]. In our experimental setup we used a Nissan e-NV200, equipped with an OBDII-Bluetooth interface (elm327) and a dedicated Android app for monitoring the following parameters, which are significant to the problem:

- *Date/time*, in the default format or in the format selected by the user.
- *Gids*, indicates the energy stored in the battery (State of Charge) as a percentage. Nissan multiplies this number by 80 Wh to get the current HV battery capacity.
- *SOC*, State of Charge (SOC) of the battery. Divide this number by ten thousand to get the value %.
- *Ahr*, battery capacity.
- *QC*, number of quick charges.
- *Ambient*, Ambient temperature comes from the vehicle's outside temperature sensor and in Fahrenheit.
- *SOH*, The State of Health of the Battery in percent.
- *Chrg Pwr*, charging power injected in the vehicle in W.

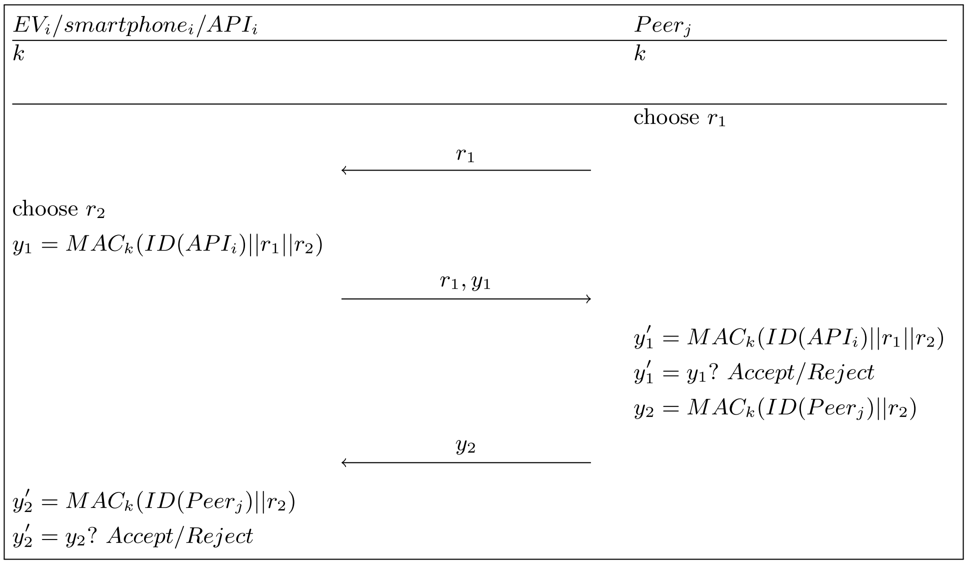

Fig. 3. Mutual authentication scheme with a challenge/response mechanism.

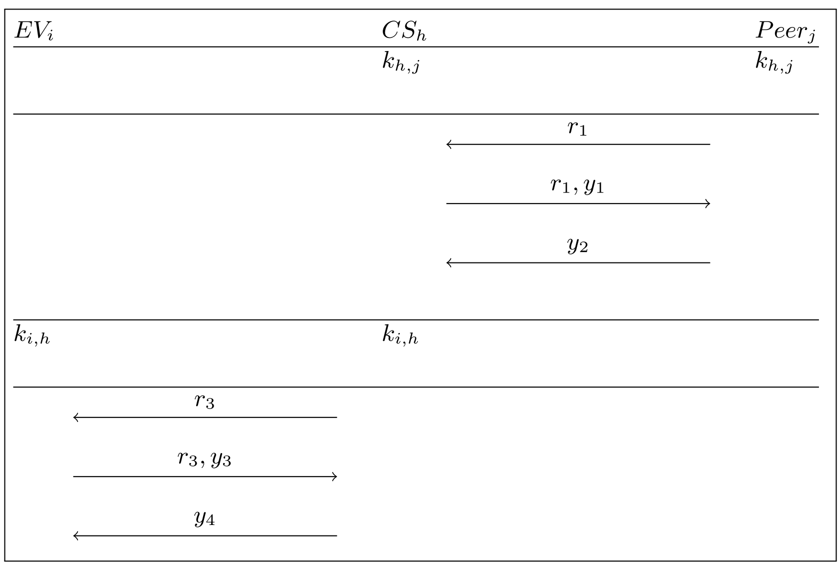

Fig. 4. Simplified challenge/response mechanism for multi-hop mutual authentication.

- *Plug State*, status of the charging port socket, that be 0, 1, 2 for not connected, partially connected, and connected.
- *Charge Mode*, 0 for not in charge, 1 for level 1 charge (100–120 V), 2 for level 2 charge (200–240 V), 3 for level 3 fast recharge.
- *Gear*, gear position, 0 for not yet read, 1 for Park, 2 Reverse, 3 Neutral, 4 Operation, 7 B/Eco.

As mentioned above, data grabbed from the EV and the charging station are sent to the blockchain platform through the validating smart contract. Fig. 2 show the flow of data from the vehicle, through the OBDII, the smartphone and the blockchain. In this case, the smartphone hosts a client application for connecting to the blockchain and storing information that are relevant both to aging and to V2G services provision. When the vehicle is connected to the charging station, the blockchain is fed by the owner of the charging station. A unique identifier for the vehicle allows a simple smart contract to collect all the information related to a given vehicle. The charging station is accessed through an OCPP server and data for the single V2G event are stored on the V2G channel of the blockchain.

Fig. 5 shows the flowchart of the implemented smart contract. Input data come from the OCPP server and from the mobile+OBDII setups. Once connected to the vehicle, through the bluetooth module integrated in the device, it is possible to get the vehicle log data via python application and to send them using a web RESTful service for interacting with the blockchain.

There are two conditions required to start the monitoring of the electric vehicle; first, when the vehicle is connected to the charging station and thus the data is collected via OCPP servers; and second, when the vehicle is not connected to the charging station and provides its parameters via the OBD. In both configurations, a special application sends the data to the blockchain through a RESTful web service running on the nodes, which also allows for read and write operations so that we can have constant monitoring of the parameters.

The Smart contract shown in Fig. 5 implements the logic of the monitoring scenarios. The first phase is the control of the Gear parameter of the vehicle, from which we can see if the vehicle is parked (Gear = 0), stationary (Gear = 1) or moving (Gear > 1). When the vehicle is parked, through the Plug State parameter it is possible to verify if the vehicle is connected to the column (Plug State = 2) or not

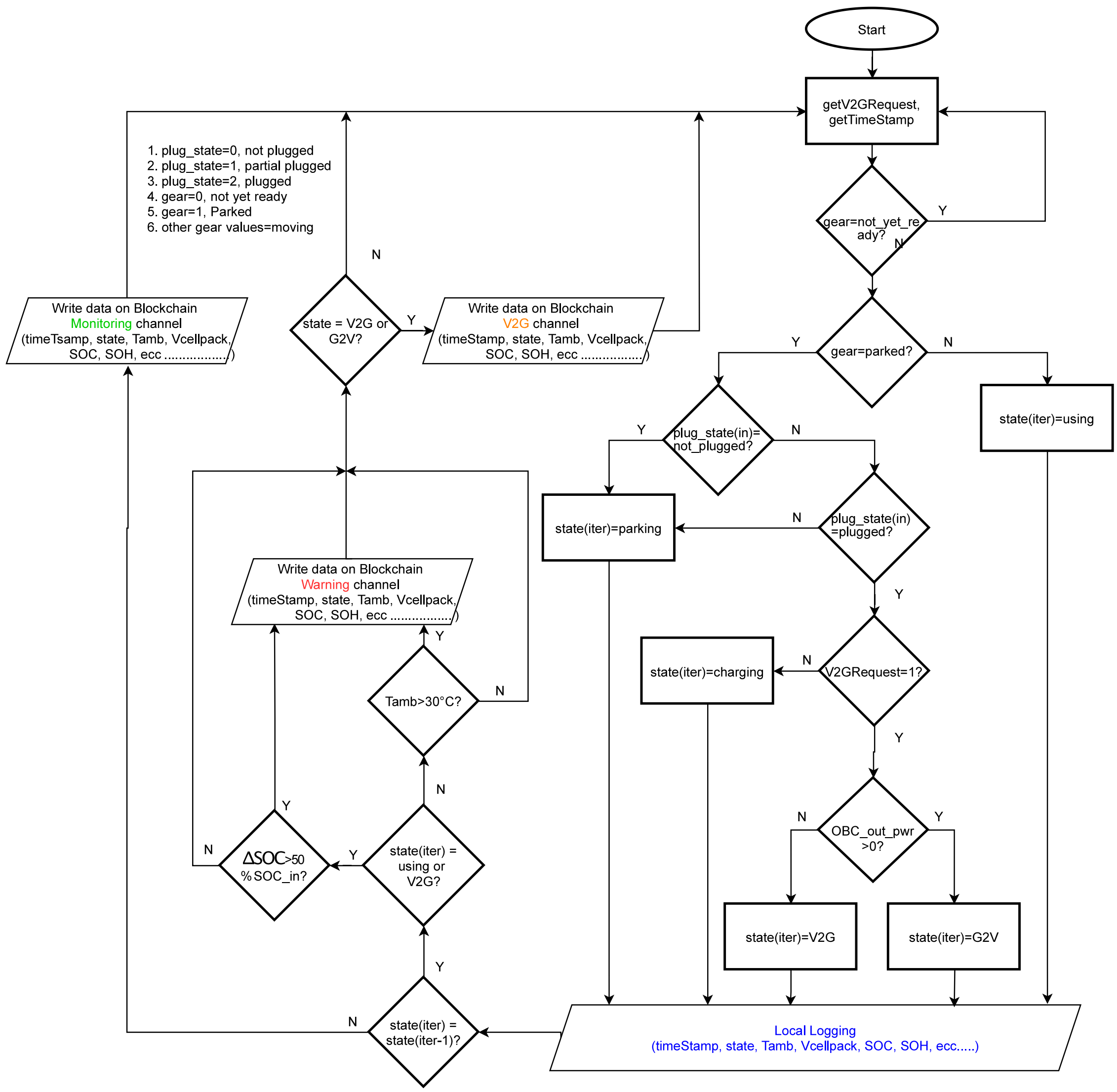

Fig. 5. Smart contract flowchart implemented for battery health monitoring and V2G services provision.

(Plug State = 0). During the connection, the battery temperature, the ambient temperature, the variation of the vehicle charge profile, the SOH of the vehicle and the voltage applied to the cells of the battery pack are monitored. Based on these parameters it is possible to define if the vehicle battery has been subjected to stress. Monitoring these parameters therefore allows to always know what is happening when the vehicle is being charged. If the limits allowed by the control logic are exceeded, these parameters are stored in the warning channel that takes into account all the events that may lead to battery aging. In addition, when the vehicle is charging, based on the sign of the power flow (injected or withdrawn), it is possible to distinguish whether the vehicle is participating in a V2G or G2V event. This information is continuously stored in the monitoring channel, making it possible to keep track of all events that have affected the vehicle and also taking into account the time spent in that particular state. When the vehicle is in a state other than a charged state, monitoring is carried out through the OBD which allows information to be received on the variation of the vehicle charge and its temperatures. This makes it possible to carry out a diagnosis of the vehicle also on the basis of the driver's driving style so as to be able to record in the warning channel any excessive discharges or any increase in temperature due to an excessive supply of energy.

The following sections show the results obtained on battery usage certification and V2G service applications.

7. VPN management

To guarantee privacy and security, it was established a site/multi-site VPN over public data networks, between sites of the GARR network for research and sites on the public Internet. The VPN allows to set a private network creating safe tunnels on the network providing authenticity, privacy, reliability and integrity of data transmission. Blorin uses a VPN managed by ZeroTier (ZT), a virtualization platform that offers VPN as a Service allowing to connect devices with end-to-end cryptography (see Fig. 6). The installation of ZeroTier One and the running the VPN are easy tasks summarized as follows: [43]:

- Creation and verification of an account on https://my.zerotier.com/
- Creation of a network on https://my.zerotier.com/network
- Download ZeroTier on the devices to be added to the network
- Adding devices as members.

8. Battery aging

This application allows an ordinary user, insurance agencies, and sellers to monitor the health of the EVs battery and thus get a proof about the vehicle aging state. One of the issues that has prompted more

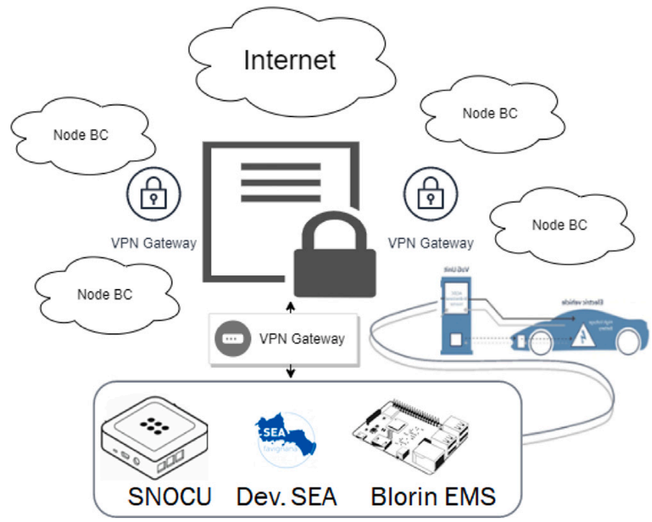

Fig. 6. Blorin architecture for VPN management.

Table 3
Experimental setup for battery aging evaluation.

Charging station	AME electrical V2G 3p10 kW DC output power : +10 kW/−10 kW Comm. protocol used : OCPP 1.6
OCPP server	SteVe 3.4.8
Vehicle	Nissan e-NV200 Battery max power: 50 kW Battery capacity: 40 kWh
Interface Phone Phone app	OBDII Bluetooth model ELM 327 Samsung A50 Car scanner ELM OBD2

attention on the topic indeed is battery aging, especially as vehicles can be used to provide energy services to the grid such as it happens in V2G programs. In this regard, it is important to distinguish the different phenomena that define electric vehicle's aging. Such phenomena can be divided into natural degradation over time and those that lead to fast degradation of battery performance (i.e. capacity fade) provoked by contemporary particular values of temperatures and SoC during parking (calendar) and aggressive charging and discharging profiles (cycling). The most significant degradation factors that accelerate battery degradation and reduce battery lifetime are:

- High ambient temperatures (higher than 30 °C) have the worst influence on battery health;
- Higher charging rates for fast charging;
- High and frequent discharging rates for excessive participation in V2G events and fast frequency regulation;
- Overcharges and deep discharges.

The experimental setup for monitoring the battery aging is composed as reported in Table 3.

Using the reading of the parameters coming from the electric vehicle, it is possible, by updating the blockchain, to analyze and monitor the state of degradation of the battery inside the vehicle, through a dedicated smart contract that allows the monitoring of the state of health of the vehicle itself.

9. Experimental results on battery usage and V2G certification

In this section, the V2G service certification, supported by the proposed blockchain platform, is carried out. The grid operator notifies on the blockchain an order of load decrease/increase in a given timeframe and the vehicle charging is stopped/started/reversed.

An example of an informational asset, as defined within the smart contract, is reported in the following listing.

```
const asset = {
  ID: id,
  DataBC: dataBC,
  Data_log: timeLog,
  Lat: latitudine,
  Long: longitudine,
  Speed: speed,
  Gids: gids,
  SOC: soc,
  Pack_Volts: pack_volts,
  Pack_Amps: pack_amps,
  Avg_CP_mV: avg_cp_mv,
  Pack_T1_C:  pack_t1_c,
  Pack_T2_C: pack_t2_c,
  Pack_T3_C: pack_t3_c,
  Pack_T4_C: pack_t4_c,
  Odo: odo,
  QC: qc,
  L1_L2: l1_l2,
  Ambient: ambient,
  SOH: soh,
  Plug_State: plug_state,
  Charge_Mode: charge_mode,
  Gear:  gear,
  Motor_Temp: motor_temp,
  Inverter_2_Temp: inverter_2_temp,
  Inverter_4_Temp: inverter_4_temp,
  I_time_stamp_state0: i_time_stamp_stat0,
  I_time_stamp_state1: i_time_stamp_stat1,
  I_time_stamp_state2: i_time_stamp_stat2,
};
```

This type of asset allows to acquire the parameters coming from the logs by adding relevant information, such as the persistence of a certain state in order to gain insight of the operating state, also on a time dimension. The update of these parameters allows the calculation of the change in the state of charge and allows to monitor the temperature outside the vehicle, thus monitoring values beyond permitted thresholds in the appropriate Alarms or warnings channel. In summary, this piece of smart contract allows to certify that the vehicle has been properly monitored in all its parameters. The latter are useful to assess the state of health of the vehicle, to check for how long the vehicle participates in the V2G or stays parked at a given temperature and state of charge and therefore can certify a misuse of the battery. This helps to keep track of the SOH of the battery and to highlight which factors have led to its degradation.

The experiments have been carried out in the SMGLAb and SNAPPLab at the University of Palermo, respectively for the initial emulation of the V2G charger with a storage interfaced through a converter to the grid and for the blockchain. Experiments have been run also at the Favignana island, for the monitoring of the aging, with real data from our e-NV200 Nissan and the AME bidirectional charging station, as shown in Fig. 7.

The reading of the logs was carried out using a python script, then data were sent to the blockchain platform through an API server listening to one of the hosts participating in the service. Then the smart contract (chaincode) was executed and calculated all the variables useful for checking the state of health of the vehicle and then finally displayed on a suitably developed Webapp. Once the parameters have been updated, the execution of various functions such as the control of the temperature and the variation of the ΔSOC, thus allowing to update the warning channel for any excessive temperature increase and/or steep variation of the ΔSoC outside the established ranges.

Furthermore, on the main channel, in addition to displaying the update of the parameters coming from the vehicle, four other parameters are processed and subsequently printed. The latter allow to give a time reference and to monitor how long a vehicle remains in a certain state.

Fig. 7. Part of the experimental setup in the Favignana island, the bidirectional charging station from AME and the NV200 electric vehicle.

Listing 1: Example of parameters read from the blockchain via API server


```
{
  "ID":"env200-fav",
  "DataBC":"Wed, 19 May 2021 16:16:07 CEST",
  "Data_log":"04/12/2021 14:56:21",
  "Lat":"37 55.6873",
  "Long":"12 19.7271",
  "Speed":"0.0",
  "Gids":"467",
  "SOC":"933001",
  "Pack_Volts":"395.00",
  "Pack_Amps":"-0.0",
  "Avg_CP_mV":"4117",
  "Pack_T1_C":"17.2",
  "Pack_T2_C":"17.0",
  "Pack_T3_C":"18.0",
  "Pack_T4_C":"17.4",
  "QC":"3",
  "L1_L2":"8",
  "Ambient":"18.0",
  "SOH":"99.16",
  "Plug_State":"0",
  "Charge_Mode":"0",
  "Gear":"4",
  "Motor_Temp":"70",
  "Inverter_2_Temp":"40",
  "Inverter_4_Temp":"40",
  "I_time_stamp_state0":"01/01/2021 00:00:00",
  "I_time_stamp_state1":"04/12/2021 14:48:21",
  "I_time_stamp_state2":"04/12/2021 14:52:50"
}
```


Our web app, whose exemplary view is reported in Fig. 9, is connected to the smart contract for getting data. It gives the actors visibility of the different warnings and data. In Fig. 8, a typical message sent by the platform to the service requesting it is illustrated, showing the timestamp of the last event, the state transition etc.

10. Conclusions

In this paper, we consider V2G and EV management with a specific focus for transparency of transactions. For this reason, starting from the assumption that more parties with contrasting interests may be involved, a blockchain-based platform has been developed and presented. In this way, data divided into channels are shared among all actors that are involved in the operation of an electric vehicle. This shared information is used for assessing the health state of the vehicle's battery, for supporting the owner for a careful use of the vehicle and for remuneration in Vehicle-to-Grid programs. Things indeed have been related and the EV owner can have a clear representation of what is going on. Using a blockchain and appropriate smart contracts we have demonstrated how to create, validate and share profiles of battery usage among the actors involved in the life cycle of the EV battery. The technology is privacy preserving for the owner and guarantees the compliance to suitable charging and discharging modes. A dedicated alarm channel rises warnings that are visible to the insurance company providing information about the owners' habits, in the same channel, the car manufacturer could also grab data useful for different business models implementation. The approach aims at creating a blockchain-based ecosystem around electric vehicles especially as these are called in modern electric systems to provide grid services. A proof of concept based on a cyber–physical infrastructure is implemented and accurately described in the paper.

CRediT authorship contribution statement

Alessandro Augello: Acquisition of data, Analysis and/or interpretation of data, Writing – original draft, Writing – review & editing. **Pierluigi Gallo:** Conception and design of study, Analysis and/or interpretation of data, Writing – original draft, Writing – review & editing. **Eleonora Riva Sanseverino:** Conception and design of study, Analysis and/or interpretation of data, Writing – original draft, Writing – review & editing. **Gaetano Sciabica:** Acquisition of data, Analysis and/or interpretation of data, Writing – original draft, Writing – review & editing. **Giuseppe Sciumè:** Conception and design of study, Analysis and/or interpretation of data, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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```
{"response":"{\"ID\":\"env200-fav\",\"DataBC\":\"Fri, 14 May 2021 19:19:07 CEST\",\"Data_log\":\"04/12/2021 14:56:21\",\"Lat\":\"37 55.6873\",\"Long\":\"12
19.7271\",\"Speed\":\"0.0\",\"Gids\":\"467\",\"SOC\":\"933001\",\"Pack_Volts\":\"395.00\",\"Pack_Amps\":\"-0.0\",\"Avg_CP_mV\":\"4117\",\"Pack_T1_C\":\"17.2
\",\"Pack_T2_C\":\"17.0\",\"Pack_T3_C\":\"18.0\",\"Pack_T4_C\":\"17.4\",\"Odo\":\"941\",\"QC\":\"3\",\"L1_L2\":\"8\",\"Ambient\":\"18.0\",\"SOH\":\"99.16\",
\"Plug_State\":\"0\",\"Charge_Mode\":\"0\",\"Gear\":\"4\",\"Motor_Temp\":\"70\",\"Inverter_2_Temp\":\"40\",\"Inverter_4_Temp\":\"40\",\"I_time_stamp_state0\
":\"01/01/2021 00:00:00\",\"I_time_stamp_state1\":\"04/12/2021 14:48:21\",\"I_time_stamp_state2\":\"04/12/2021 14:52:50\",\"Time_stamp\":\"0:0:1:12:\"}"}
```


Fig. 8. Example of parameters read from the blockchain via API serve.

Fig. 9. A screenshot of the web application developed with Exalto srl.

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