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BANULA—A Novel DLT-Based Approach for EV Charging with High Level of User Comfort and Role-Specific Data Transparency for All Parties Involved

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Abstract: The core goal of the BANULA research project is to combine customer-oriented and grid-compatible charging of electric vehicles. It addresses the current challenges of the e-mobility ecosystem from the perspective of grid operators and charging infrastructure users and creates added value for every mass market role involved. In the project, the idea of a virtual balancing group based on blockchain technology is implemented. Thereby, it enables extended data acquisition, a real-time data exchange between grid and market participants, proper balancing and grid node-specific load flow determination and, thus, load management.

Keywords: charging; power supply infrastructure; mass market; data acquisition; load management

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1. Introduction

One of the major challenges on the pathway to a high penetration of electric vehicles (EV) is the ramp-up of a widespread and reliably available charging infrastructure. Due to the need to significantly expand the number of charging stations, the construction of public charging stations has been strongly promoted in Germany and other European countries over the course of recent years. In this context, various publicly funded programs, such as "Publicly accessible charging infrastructure for electric vehicles in Germany" [1], have been established to create incentives for the erection of charging infrastructure. As a result, the number of charging points in Germany has steadily and significantly increased. Quantitatively, the number of public charging points has increased from 17,108 in 2018 to 77,191 in 2022. In 2022 alone, over 28,000 charging points were installed. The strong expansion of public charging infrastructure affects both AC charging as well as DC fast-charging stations. Some 20% of the expansion of charging stations in 2022 in Germany were DC fast-charging stations [2].

Despite this rapid growth in the number of public charging points, great efforts still have to be made to further increase the number of accessible charging points in order to meet an ever-increasing demand from the sharply rising number of electric vehicles in the German market. Estimates for the required number of public charging points range from 350,000 [3] to one million [4] in 2030. Similar developments with respect to the need for charging stations and growth of the latter, as well as the EV market, can be observed in other European countries, such as France and the Netherlands [5,6]. The US is also planning a significant expansion of charging infrastructure in the upcoming years [7] and, hence, has also allocated a significant amount of government funds.

In addition to a high number of charging points, easy and, most of all, reliable access to charging infrastructure for end customers is an indispensable requisite for the success of e-mobility as a whole. In order to use public charging stations, consumers currently conclude charging contracts with e-mobility providers (EMPs), thereby gaining access to all available charging stations within their direct charging network. Most providers offer roaming contracts so that their customers are capable of charging their electric vehicles using the infrastructure of other third-party providers [8]. Moreover, the EMP is responsible for pricing and billing of charging processes as a service towards end users as well as third party CPOs. These CPOs are responsible for operating their charging stations and able to exert influence on the operation, taking legal, economic and factual circumstances into account. Both market players, therefore, enable users to charge electric vehicles as a combined service.

However, there is significant potential to improve the current charging and billing processes between the market participants involved. Users often lack certainty about the exact roaming and billing conditions for charging stations of third-party providers in general and whether they can use their charging contract with a specific charging station at all. In addition, users are forced to conclude specific charging contracts—just like gasoline charge cards nowadays– and cannot use their household electricity contract. Moreover, the lack of usage of forecast data places a disproportionate burden on CPOs regarding the acquisition of the correct amount of energy for their charging stations—unless they are eligible for balancing using synthetic profiles. This, however, is not a feasible pattern for a full-scale market penetration of EVs for various reasons.

Finally, distribution grid operators (DSO) need full transparency in terms of location, power and energy load with regard to occurring charging processes in their grids, all of which are not available at the time being. This will dramatically gain importance, as millions of charging points are to be accommodated by power grids.

This paper proposes a solution to the issues raised. We present a block-chain approach, building upon distributed ledger technology and yielding solutions to the challenges of all players involved: costumers, charging point operators, distribution as well as transmission system operators, e-mobility providers and balancing group managers.

In June 2023, parts of this research were presented at the EVS36 Symposium in Sacramento, USA.

Past and Ongoing Research Activities

Within the BANULA project, the authors are particularly addressing the development and applicability of a novel and innovative e-mobility ecosystem from the perspective of a multitude of stakeholders. It also focuses on the applicability of communication and control of charging points of the current system in the BANULA ecosystem via blockchain. From today's perspective, the charging electricity is allocated on the balance sheet of the supplier of the charging infrastructure operator. In this model, the charging station of the charging infrastructure operator fills the role of the final consumer. However, completely removing the e-mobility provider from responsibility for the balancing and forecasting of charging processes is neither goal-driven for a correct balancing group management nor does it reflect reality. The first, as yet imperfect, approaches to a solution are offered by the German E-Mobility network usage contract [9]. In essence, this involves the allocation of the electricity quantities drawn from the grid to the balancing group of the respective e-mobility provider rather than to the balancing group of the charging infrastructure operator in accordance with MaBiS (Market rules for the execution of balancing group settlement electricity). In addition to the costs of the charging current, this also affects the network charges, in particular the provision of corresponding power, as well as the costs of construction, maintenance and upkeep of the actual infrastructure. Our research includes the creation of transparency for the availability of measurement and billing data in real time, the reduction of contractual complexity with roaming providers or in the context of roaming, the simple routing of costs for the construction and operation of the infrastructure and network charges, and the allocation of costs according to the source.

Many of these issues have been addressed in recent years, but the challenge of a comprehensive and user-friendly charging infrastructure has so far only been inadequately solved (Triebke et al. [10]). Kihm and Trommer [11] model the future market for electric vehicles as well as the associated substitution of conventional energy sources with respect to the use of electric vehicles. The authors have emphasized that both the charging infrastructure and a coherent regulatory framework for corporate customers are important elements for the diffusion of electromobility. However, the study merely considers financial aspects from the user's perspective and, thus, does not address either local or system-allocated effects of the diffusion of electric vehicles. In general, electric vehicles for load management are widely viewed positively. Lopez et al. [12] simulate the load shifting of individual electric vehicles and the resulting load-smoothing possibilities incentivized by minimizing the purchase costs for electricity. By doing so, they demonstrate the suitability of electric vehicles for load management. Babrowski et al. [13] analyze the load-shifting potential of electric vehicles and additional implications due to the availability of charging infrastructure at the workplace. The authors conclude that load-shifting potential exists and discuss the consequences of load management deployment of electric vehicles on electricity generation. However, specific system-wide impacts are not analyzed nor quantified in detail. Also, the applicability and potential for load shifting using decentralized technologies are neither considered nor compared to centralized technologies.

Other projects focus on a large variety of aspects with regard to charging station rollout (LamA—Laden am Arbeitsplatz [14]), charging pattern optimization (eFlotten- und Lademanagement [15], Shared E-Fleet [16], eMobility-Scout [17], ChargeLounge [18], InFlott—Integriertes Flottenladen [19]), inclusion of smart meter gateways into the charging IT landscape (LamA-connect [20]), various boundary conditions of charging (C/sells [21], SPARCS [22], IMEI—Erforschung integrierter Mobilitäts- und Energieinfrastrukturen [23], GeMo—Gemeinschaftliche Mobilität [24]) and charging infrastructure as a fundamental pillar of a smart grid (Charge@Work [25]).

In the referenced projects, the existing roles, involved parties and systems of electromobility have been used and the functions have been embedded within the framework of the current ecosystem. This existing ecosystem is to be expanded and combined with the ecosystems of the energy grids and markets. For this purpose, new roles, processes, responsibilities and systems are to be defined and developed, and a new approach—based on blockchain technology—is tested to carry out charging processes. The topics of balancing group management (both technical and legal aspects) and the consideration of flexibility have also not yet been integrated into electromobility ecosystems nor implemented in blockchain approaches so far. Finally, regulation has to be adapted, very much the way the German regulator has recently put thoughts into this process of "Netzzugangsregeln zur Ermöglichung einer ladevorgangscharfen bilanziellen Energiemengenzuordnung für Elektromobilität" [26]. All these aspects are taken into consideration within the work presented as follows.

2. Materials and Methods

One objective of the project is to implement the BANULA concept in the current energy and electromobility market. Therefore, it is necessary to adapt to the methods, processes, software systems and regulations in the German energy market. In 2020, the German federal network agency (Bundesnetzagentur), as the responsible regulation authority, passed a regulation—BK6-20-160 [27]—to improve and enhance access to the electrical grid.

For electromobility, as one of the biggest new use cases in the electrical market, the NZR-EMob [26] is part of this framework. It contains cornerstones for energy quantity balancing for specific charging processes and the associated and necessary gird access rules. These new grid access rules for electromobility enable an alternative settlement model for energy quantity allocation in the balance sheet compared to the approach used today.

The BDEW-German Association of Energy and Water Industries (Bundesverband der Energie- und Wasserwirtschaft) is the largest energy industry association in Germany and represents the interests of the electricity and energy sector. The BDEW published applications rules [28] for the implementation of the above-mentioned NZR-EMob in the

German energy sector. These application rules are a current vehicle for the BANULA ecosystem and will be laid out below. The BDEW has formulated a process description entitled “Model 2 for balancing energy quantity allocation options for specific charging processes”. Within the BDEW application rule, Model 1 (Figure 1) describes the current balancing model and Model 2 (Figure 2) describes the options under the NZR-EMob.

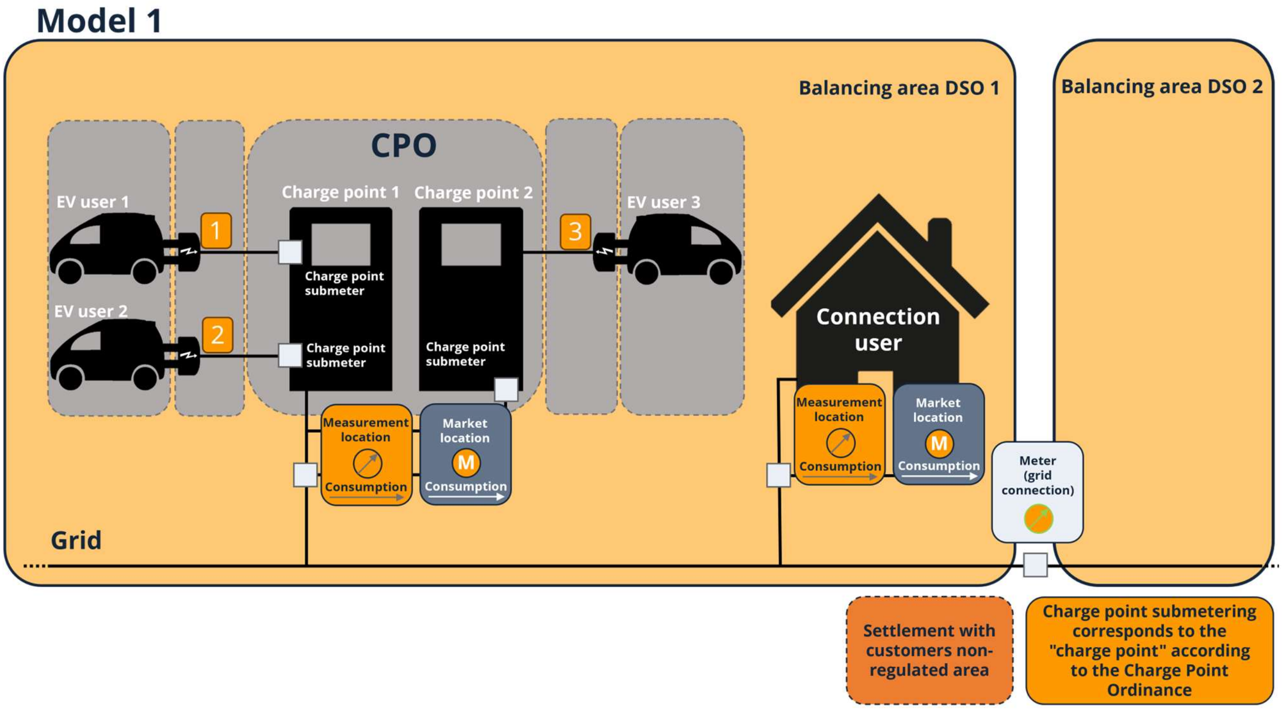

Figure 1. Model 1 is based on NZR-EMob and within the BDEW application rule, Model 1 describes the current balancing model in the actual energy market where the charge point is handled as a usual consumer. Two charging processes (1, 2) are carried out at charging station 1 and one charging process at charging station 2 (3). Each charging process is measured by the charge point register and the complete energy is measured by the measurement location. The energy of each charging process is balanced by the charge point owner via standard load profile [28].

As a basis for the description of Model 2, the BDEW used the already established market communication processes for business processes for the supply of electricity to customers (GPKE) [29], switching processes in electricity metering (WiM Strom) [30] and the market rules for the implementation of balancing group billing for electricity (MaBiS) [31], which were adapted in relation to electromobility. Only a few new market communication processes were introduced for Model 2. It also only describes the processes of the energy industry, not specifically related to the electromobility sector.

While the energy quantity of the market location is balanced in the already established settlement model, Model 2 provides for a charging process-specific energy quantity allocation on the balance sheet. In Model 2, the energy quantity of the market location is no longer balanced, but treated like a grid time series in terms of balancing and a charging process-specific balancing energy quantity allocation takes place in the balancing area of the charging point operator. This means that the charging point operator must ensure a balancing group allocation for each charging process in its balancing area. The distribution system operator no longer has balancing responsibility for the market location registered in Model 2. The charging point operator is, therefore, obliged to register a balancing area in the corresponding control area with the balancing coordinator. The balancing area of the charge point operator is not limited to the grid area of a distribution grid operator. Balance discrepancies (delta quantities) must be borne by the balancing group manager of the balancing area and market locations that are to be settled in accordance with Model 2 must be reported to the respective distribution system operator.

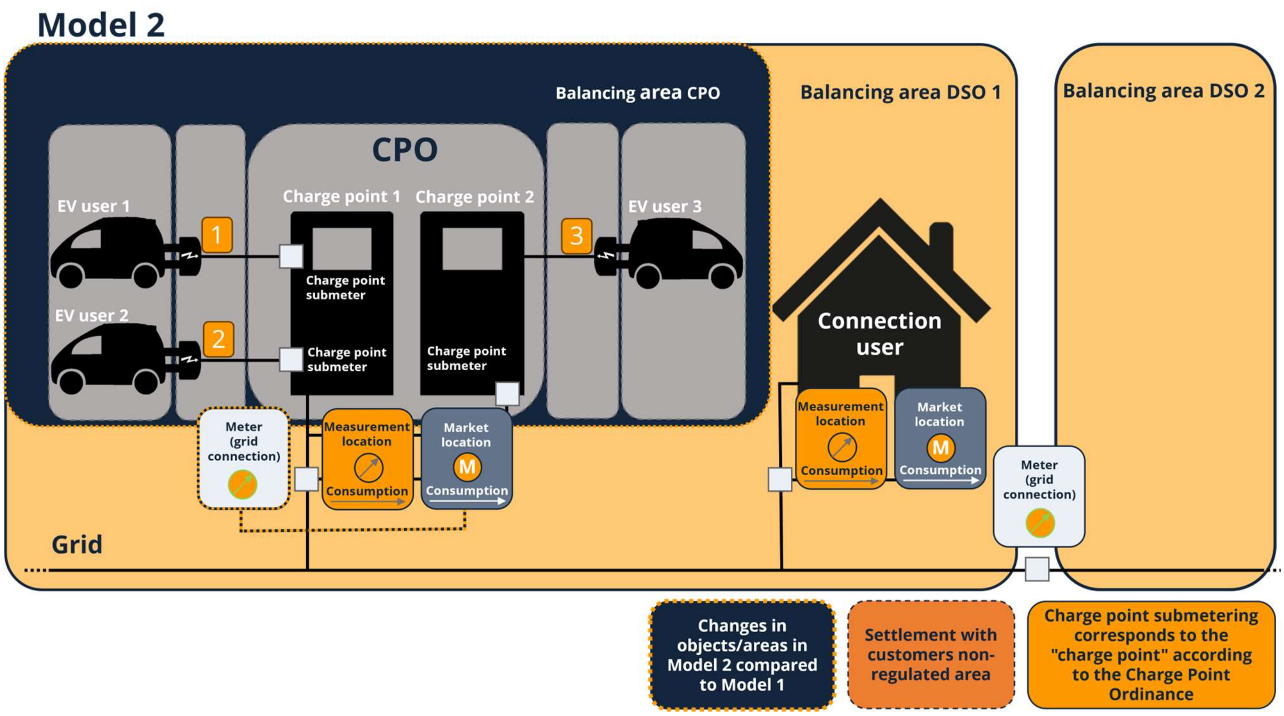

Figure 2. Model 2 describes the options under the NZR-EMob, which are balancing energy quantity allocation options for specific charging processes. The charge points are removed from the balancing area of the DSO 1 and added to the balancing area of the CPO. Two charging processes (1, 2) are carried out at charging station 1 and one charging process at charging station 2 (3). Each charging process is measured by the charge point register and the complete energy is measured by the measurement location. The energy of each charging process is balanced by the charge point operator, based on the measurements of the new meter [28].

General rules for both models:

- A market location can only be assigned to one model at a time, either Model 1 or Model 2.
- The following applies to the commissioning of a market location with the consumption type "e-mobility charging station".
- The nonstandardized "new installation" process is carried out as for any other market location according to the principles of the respective distribution system operator.
- In the new installation process, the market location is initially assigned to Model 1 by the DSO.
- To participate in accordance with Model 2, the charging point operator must apply for and use the IDs relevant to the corresponding role (market partner ID and electricity grid operator number) from BDEW.
- The ID of the market location and the ID of the metering location remain unchanged regardless of the model assignment.

Additional regulations for Model 2

- Balancing of the energy quantity of the market location in the balancing area of the distribution system operator does not take place. Instead, the energy quantity of the market location is balanced via a grid time series between the balancing areas of the distribution system operator and the charging point operator.
- The distribution grid operator is the grid operator responsible for the grid time series. The charging point operator is the neighbouring grid operator.

- The energy quantities of the charging processes in the balancing area of the charging point operator are balanced.
- The charging point operator has the aggregation responsibility for the energy quantity of the charging processes in the charging point operator's balancing area.
- The energy quantity of a charging process can only be allocated to one charging point operator's balancing area.
- The change of supplier within Model 2 is currently not procedurally structured and must be carried out bilaterally.

As the BANULA concept deals with personal data between multiple parties that may not trust each other, a distributed and trustworthy technology is to be used for data access and proof of validity: Distributed ledger technology (DLT). DLT is a concept that aims to store and manage data in a decentralized manner. Unlike traditional centralized systems, where a central authority or institution has utter control over the data, DLT enables distributed storage and processing of information across a network of participants. This is achieved through the use of cryptography and consensus-based mechanisms that allow participants to agree on a common data consensus without the need for a central authority. As a result, DLT offers a high level of transparency, security and resistance to failure and tampering.

A well-known example of DLT is blockchain technology, which was first introduced in Satoshi Nakamoto's white paper "Bitcoin: A Peer-to-Peer Electronic Cash System" [32]. In addition to the public blockchain, there is also the so-called permissioned blockchain, in which network participants must be approved in advance. This ensures a certain degree of privacy and control over the network. Permissioned blockchains are used in sectors such as financial services and corporate environments where special compliance requirements and data protection regulations apply.

3. BANULA's Concept

The fundamental concept of the BANULA ecosystem is a holistic approach to combine energy economic processes and energy balancing, on the one hand, with the commercial processes in the e-mobility framework on the other hand to make them both more efficient in favor of the end customers and the electricity market roles. BANULA provides correct accounting between all parties involved as they have to implement a new common communication network.

Within this new ecosystem, charging point operators provide their infrastructure to e-mobility service providers and do not need to procure the charging electricity. This may sound arbitrary at first; however, the consequences are profound. The e-mobility providers have to procure the necessary charging electricity for their own customers while at the same time benefiting the system as a whole, they are able to create much better energy procurement forecasts than charging station providers. This decreases the overall energy grid imbalances as the correct amount of energy can be purchased. Distribution system operators can use this approach to gain full transparency of the charging loads within their grid, reduce imbalances within balancing groups and improve overall energy grid stability. Moreover, balancing errors are no longer to be covered by grid operators. In short, errors that are the responsibility of the e-mobility service providers are to be met physically or financially, the latter imposing a strong incentive for correct balancing.

Operationally, in order to meet current regulations, within BANULA, a virtual grid area is implemented in which all charging points relevant operated through an EMP are aggregated by the charging processes of its customers.

BANULA acts as the operator of this virtual grid area and is in direct exchange with the adjacent physical distribution system operators in order to coordinate grid operator processes directly with each other. The management of the charging energy (in terms of energy balancing groups) is carried out by any number of EMPs and not by a single supplier who supplies the physical grid connection point to which the charging infrastructure is connected (An example from the concrete application would be a charging process at a

LamA charging point on the campus of a Fraunhofer institute by any EMP. This EMP now manages this charging point in the virtual grid for the charging time of its customer, even if the charging point is located on the Fraunhofer campus). By enabling a mechanism to decouple the supplier of the charging station and the supplier of a specific charging process, customers can choose a specific EMP for a charging process, completely independent of the CPO of the charging infrastructure and EVSE they want to use. Thus, an EMP always balances the charging current withdrawals of its customers based on the authentication at the charging station (e.g., by means of RFID) in terms of a different accounting allocation. Against the background of this approach, it becomes necessary for the EMP to ensure correct balancing group management—with regard to the charging processes of its customers. This is a major contribution to ensuring system stability while further increasing the charging capacities of electric vehicles through a proper allocation of balancing responsibility. As stated earlier, by shifting the balancing responsibility to the EMP, the costs of balancing errors are reduced for the grid operator. In this way, costs and risks can be allocated appropriately. The EMP's designated balancing group is assigned the withdrawals of a large number of charging points depending on the usage behaviour of its customers.

To implement BANULA's novel ecosystem, blockchain technology is used to provide a data architecture that all participants in the ecosystem can use and build upon (For more properties that distinguish a blockchain, see Section 4). This corresponds to a back-end system of market communication in order to be able to allocate charging energy quantities to the supplier or suppliers of charging electricity within the 15 min period relevant for balancing. Blockchain technology, as a decentralized medium, manages and regulates the interaction of the different parties involved. It enables a timely, accurate, tamper-proof and transparent allocation of the

- charged energy quantities per charging pole,
- customers to the balancing groups,
- balancing areas,
- duration of use as well as data necessary for the billing of the grid usage.

It also offers the opportunity to integrate information about the network status into the charging management of the EMPs.

For grid operations, it offers opportunities to balance the provision of flexibility on a plant-by-plant basis, to assign these to corresponding market roles, and to assign the intended use of flexibility usage. The coupling of the grid (transmission system operator, distribution system operator) and the market (electric mobility provider, balancing group coordinator), thus, provides a data and information interface to communicate grid events and restrictions directly to the market in accordance with German regulation (§ 13(2) EnWG). The overall system with the interfaces and information to be exchanged is shown in Figure 3.

As far as the issue regarding customers of an arbitrary EMP charging at any charging infrastructure of a given CPO is concerned, in the novel BANULA ecosystem, a charging process works as follows:

1. A given client establishes a contract with fixed terms (i.e., cost per kWh) with an arbitrary EMP. The client's authentication dataset is assigned to its respective EMP in a decentralized DLT/blockchain network. The client is now capable and eligible to use any charging point, which is part of the decentralized virtual grid area.
2. In order to start a charging process, the client carries out the authentication process either via presenting an RFID, registering in a mobile app or through "plug and charge" building upon an implementation of the ISO 15118-1:2019 standard [33]. Through the DLT network, the client's authentication and eligibility to be granted access to the charging point in question are verified. If all criteria are met, the charging process is enabled, and the respective kWh are assigned to the EMP's energy economic balancing sheet.

3. The charging process starts, in parallel, the BANULA-DLT network aggregates all relevant data, e.g., typical charge detail records for other participants in the ecosystem, such as charged energy, time stamps, etc. The respective EMP as well as the distribution system operator (DSO) in whose grid area the event takes place are both provided with the time series data of the charging process. The CPO whose charging point was used is provided with the data needed in order to bill the use of the charging infrastructure, i.e., the contribution margin to its fixed costs.
4. Following this process, the DSO has complete knowledge of all charging processes within its grid. Moreover, this information is available for each charging point in real time, which in turn enables the DSO to gain a better understanding of load flows in the grid.
5. In order for this concept to work, all charging points are to be balanced in a so-called virtual grid, although physically, they are clearly and obviously part of a DSO's real distribution grid.
6. In complete analogy to existing processes in Germany's energy economic regulatory framework, the virtual system operator establishes a summarized load time series on a monthly basis for each EMP in a temporal resolution of 15 min. This time series data are used for an exact ex post balancing of the charged kWh for each EMP. Where applicable, upstream and downstream grid operators can tap the same kind of summarized load time series data for their balancing purposes. If applicable, EMPs are subject to financial punishment for any physical deviations compared to their balancing sheets.
7. Because real-time charging information is available, grid congestion can be determined in time and further developments using i.e., artificial intelligence farther down the road will allow for predictive grid management e.g., by establishing incentives to charge at different times or locations.

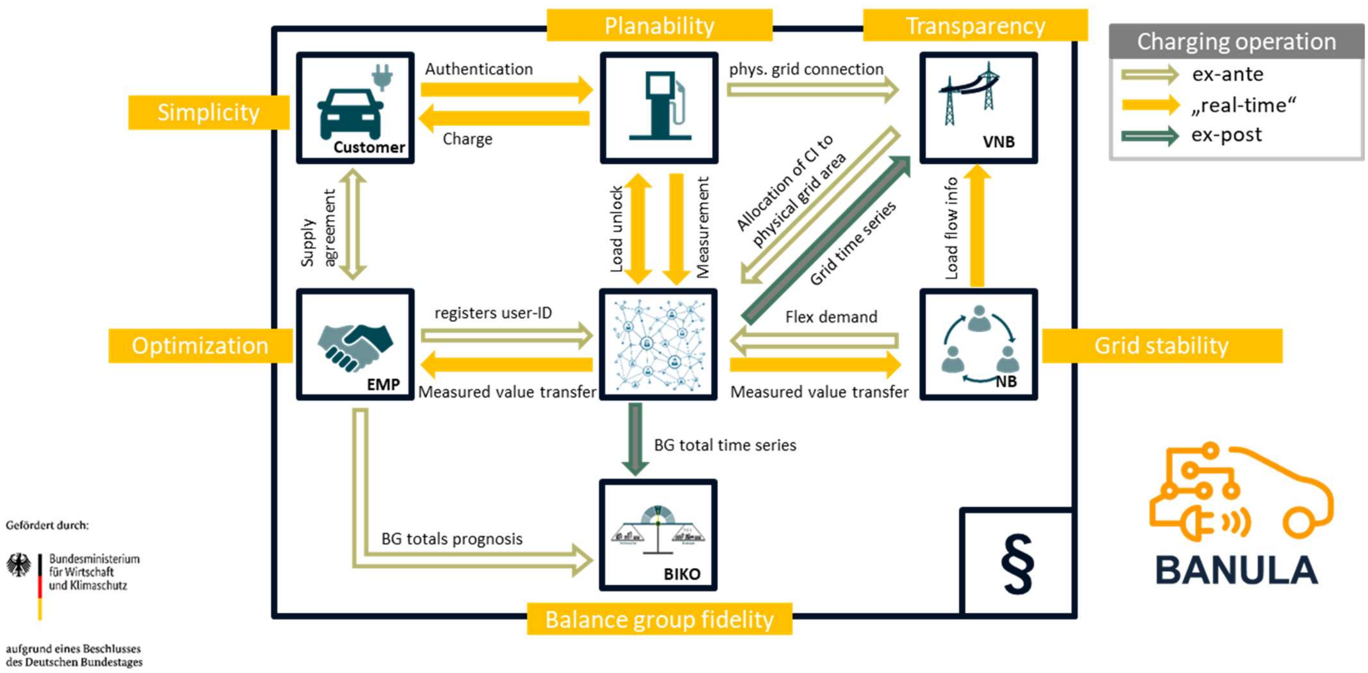

Figure 3. Brief overview of the EV charging ecosystem and the operational steps carried out during charging processes. Within the context of the BANULA ecosystem, these processes are significantly enhanced using a blockchain-based approach employing distributed ledger technology for the benefit of all participants of the system.

Figure A1 displays the proposed charging progress in the new ecosystem as a swimlane process diagram (Business Process Model and Notation 2.0/BPMN 2.0, https://www.

omg.org/spec/BPMN/, accessed on 23 March 2023). The Figure A1 shows the market participants involved and their interactions during the charging process. As indicated, data are exchanged between market participants of the energy market and the electromobility ecosystem during the charging process.

3.1. Respective Perspectives of Each Market Participant

In the current energy market and electromobility ecosystem, each market participant has its own defined role with its respective tasks, advantages and disadvantages—for its role and the entire system. The roles in the current ecosystem are defined for the time being and the companies fill these roles as their business cases. As the BANULA ecosystem aims to reduce the disadvantages of the system, it must also maintain and improve the advantages. Based on the respective role of the market participant, different perspectives need to be considered to leverage the new ecosystem in the current market.

3.1.1. End Customer

Currently, customers are free to choose any EMP, but they cannot charge with certainty after finding a charging point at a previously agreed-upon price; even at the same charging point, the costs of a comparable charging process can differ significantly depending on the EMP. In practice, users would have to check before each charging process whether they want to accept the price or continue the quest for the next charging point. If the user has explicitly concluded a contract with an EMP that includes, for example, 100% green power for charging, the guarantee of this power quality cannot, under the current regime, be mapped independently in the roaming case. In addition, it is currently not possible for customers to reliably use all available charging stations with just one charging contract.

Thus, the addressed needs for action from the customer's perspective are:

- Removal of access barriers and creation of price transparency;
- Sourcing of advertised and purchased "quality" charging power, e.g., regional, green, etc.;
- Reliable access to all available charging stations with just one charging contract,
- Usage of their own energy provider at every charging station: charge your own PV electricity—even on the road.

3.1.2. E-Mobility Provider

EMPs that enable their customers to charge on the basis of a peer-to-peer contract with a CPO or in the context of roaming have been insufficiently involved to date in the correct balancing of charging processes. Particularly in the case of roaming, there is no need for the EMP that enables its customer to charge at charging infrastructure, to make an accurate forecast under the current regime. Suppliers who provide electricity to charging stations of CPOs balance for annual withdrawals of up to 100,000 kWh using synthetic load profiles (SLP). However, proper SLPs that sufficiently consider the various use cases of the charging infrastructure and, in particular, the frequently spontaneous charging do not yet exist; even if they did, they would very likely reflect reality poorly.

Thus, the addressed needs for action from the EMP's perspective are:

- Enable access to any charging infrastructure under transparent and simple conditions;
- Establish a system that solves the access deficits of today's roaming;
- Introduce a central energy balancing group forecast of all customers across Germany or a control zone by the EMP (establishment of reliable forecasts of charging energy to be procured).

3.1.3. Charge Point Operator

The charging energy is currently assigned to the supplier of the CPO in the balance sheet. In this picture, the charging station of the CPO fills the role of the final consumer. However, completely removing the EMP from responsibility for the balancing and forecasting of charging processes, as has been the case to date, is not expedient and is the subject of heated debate within the industry. The first, as yet imperfect, approach to a solution is offered by the E-Mob network usage contract [9]. In essence, this involves the allocation of the electricity quantities drawn from the grid on a balancing group basis according to the MaBiSF, not to the balancing group of the CPO, but to balancing groups designated by the respective EMP. However, neither essential details have been specified yet, nor are technical solutions available. In addition to the costs of the charging current, this also affects the network charges, in particular the provision of corresponding power, as well as the costs of the construction, maintenance and repair of the actual infrastructure.

Thus, the addressed needs for action from the CPO's perspective are:

- Create transparency for the availability of measurement and billing data in real time;
- Reduce contract complexity with roaming providers;
- Wire through simply the costs for infrastructure construction, operation as well as network charges;
- Allocate costs according to the originator;
- Procuring and balancing of charging electricity in line with the polluter-pays principle.

3.1.4. Distribution System Operator

DSOs bear a significant balancing group deviation risk of their network groups due to the current balance sheet mapping of charging processes and have to expect high consumption peaks in distribution network strands that are currently merely inadequately measured. Furthermore, distribution grid operators do not know the charging load at certain grid points and install sensor technology to operate the grid safely.

Thus, addressed needs for action from the DSO's perspective are:

- Exploiting synergies and creating transparency: what happens where in the grid, in real time (so that grid stability measures can be initiated to minimize balancing group deviations and the necessary risk capital);
- Form appropriate aggregation points that can be forecasted and managed;
- Create incentives for EMPs to make predictable withdrawals and avoid power peaks.

3.1.5. Transmission System Operator

If the existing system is continued, the TSOs will also be increasingly exposed to uncontrolled and hard-to-predict use of balancing energy in the physical balancing of their networks. This would result as a direct consequence of schedule deviations in the downstream distribution networks.

Thus, addressed needs for action from the TSO's perspective are:

- Increase in balancing group reliability;
- Support system security through the systemic use of flexibility by managing the load in the distribution network and its IT-based proof of delivery.

4. Implementational Questions

The BANULA project initiative develops a blockchain-based data platform that enables a tamper-proofed and German-regulated billing of charging processes for all market participants. The overall purpose is to establish a new ecosystem, which will be of benefit to all players involved. The question as to who will eventually operate the system is yet to be resolved.

The main objective of the project is to make public charging points accessible to all end consumers in the most transparent terms and to best prepare all parties involved for the mass market penetration of electric cars. For this purpose, the ecosystem proposed aggregates charging points of a charging station operator in a specific grid area into a virtual charging point network. It integrates all involved market roles and enables trustworthy data exchange. Blockchain technology manages and regulates the interaction of the various players. In addition, EMPs, CPOs, DSOs and TSOs gain full transparency as to occurring charging events. This provides an accurate, tamper-proof and transparent allocation of the charged energy per charging point, per customer and balancing group, per usage period as well as the data required for the grid fees. Within our contribution to EVS 37, we would like to further discuss this approach with specialists from around the world. Within the project team, we raise the following five questions during the project duration and create guidelines for the technical implementation.

4.1. Reasoning for Blockchain-Based Approach

As an underlying communication platform, the blockchain as a distributed ledger offers security, full transparency and auditable traceability over all interactions of the participants. In addition, the blockchain is not operated by a single party, but rather operates in the form of a distributed network that "belongs" equally to all stakeholders and to rules that all stakeholders have jointly defined (governance model). New participants (market parties) can join at any time, but they can only use the system if they submit to the common set of rules (based on the rights defined by the stakeholders, e.g., by means of previously defined rights for the individual roles). By introducing digital market roles (identities), blockchain technology can be used to include market parties in their role deposited by an authority in an automated as well as standardized manner via an "authority" model. Based on the best fitting governance model for the ecosystem—which is also part of our research—a blockchain-based approach delivers the technological aspects for each role to interact with each other.

4.2. Is a Blockchain Performing Well Enough to Deliver Real-Time Results Even with a High Number of Participants?

Depending on the use case, different blockchain technologies and concepts are available. Permissioned Blockchains are only accessible to consortia and also offer transaction times for high-performance requirements that enable almost real-time processing (a few milliseconds) compared to previous matching mechanisms (approx. 15 min). However, depending on the project requirements, the use of public blockchains may also be appropriate, e.g., to ensure easy access by the public (the end users). Deciding which blockchain concepts (or combinations of them) are suitable for operational use is also part of our research. As for now, the current plan is to implement a blockchain-based approach where the blockchain itself only holds a limited set of data but offers an up-to-date lookup table for each role of the system. The blockchain—let it be called BANULA Data Hub (DHB) for now—knows all the application programming interfaces (API) for each party in the ecosystem and also the necessary rights to interact with this party, as indicated in Figure 4 below.

4.3. Can All Data in the Blockchain Be Viewed by All Actors and How Do We Ensure Data Protection and Privacy?

Depending on the blockchain technology used, there are various options for protecting sensitive data. Following the governance model mentioned above and the associated different roles, access to the data available in the BDH network and its processing options can be comprehensively regulated. For example, in Hyperledger Fabric, it is possible to separate different parts of the distributed ledger network for different use cases. In addition, encryption can be used to secure the transmission of data within these subareas. The project also investigates the possibilities for controlling access to the protection and its suitability for the different use cases. In any case, it is important that market players or all participants are only allowed to see the data in plain text for which they have authorization (e.g., EMP A only sees the measurement time series of its assigned customers and EMP B does not see these data in plain text, but only as an encrypted value for consensus building, which cannot be deciphered by EMP B). As shown in Figure 4, the blockchain works as a gatekeeper and permission management system with suitable smart contracts programmed by the government organization in the ecosystem.

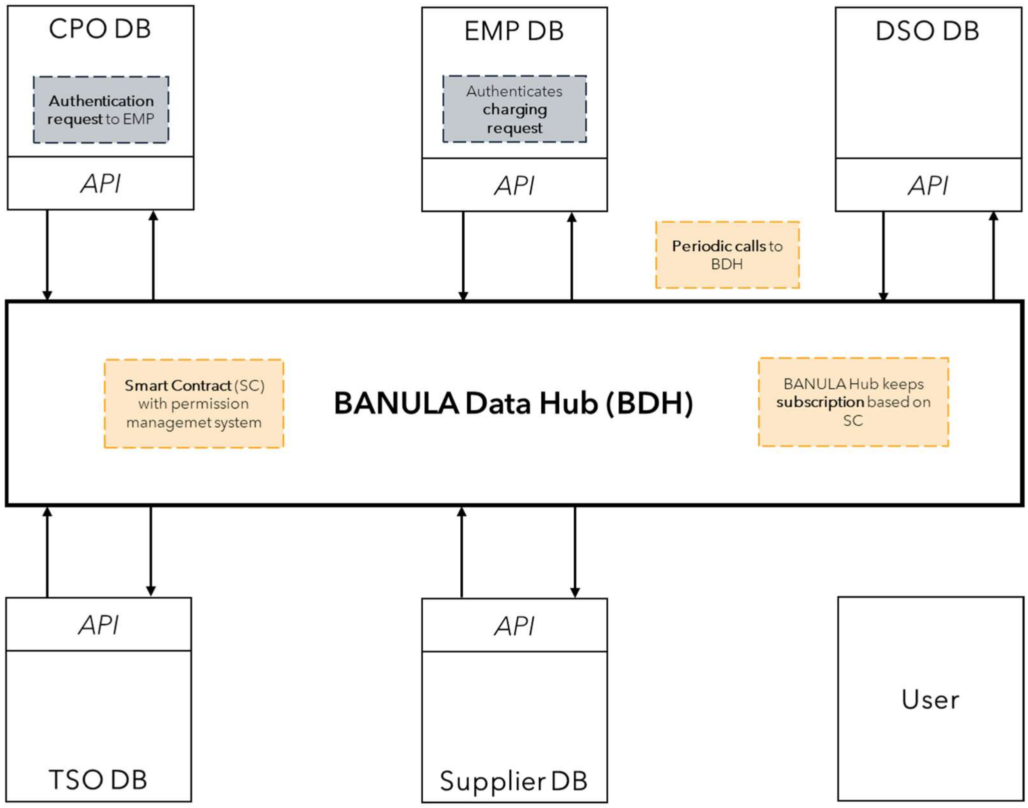

Figure 4. A schematic description of the blockchain-based approach for a DLT-based platform as lookup table and gatekeeper.

4.4. What Is the Strategy for Existing Hard- and Software Systems?

The project will develop an integration concept for existing charging points as well as new charging hardware to be set up by the Fraunhofer charging network "LamA" and the Lidl/Schwarz Group as a blueprint for the scalability of the project architecture solutions. In total, the participating project partners can so far integrate up to 10,600 charging points into the BANULA network. The solution explicitly aims to make a further inventory (outside the partners' charging networks) integrable. Overall, there are two starting points here.

Top-down: On the one hand, regulatory requirements are needed for later implementation, e.g., on the part of the regulation authorities of the German federal network agency (Bundesnetzagentur) with regard to virtual network areas concerning the network connection of charging stations. Discussions are planned here on the part of the transmission system operators. Furthermore, the topic is to be discussed within the framework of the European TSO-DSO cooperation. In the next few years, the network code flexibility is to be developed at the European level. Basic elements of our question can be directly incorporated here.

Bottom-up: Parking operators and large employers can already participate in the network today in order to achieve fair and equitable treatment of the workforce with regard to mobility subsidies (no free fuel for e-drivers) and the charging of guests.

4.5. Transfer Strategy for Europe

A decentralized solution (like DLT) also offers more flexibility than a centralized platform for onboarding additional regions (or environments). A DLT network is not subject to the sovereignty of a single provider and, due to its decentralized orientation, by definition, offers more openness for the onboarding of new stakeholders. Due to the (within the framework of the project initially Germany-wide) implementation on a national level, overarching solutions for simple loading in the virtual grid area must already be developed within the project for the four German TSO control areas. These processes are scalable across Europe, since the European TSOs are galvanically as well as information-technically coupled and the concept of the balancing group management is analogously structured. The model requires an expansion of the German (and potentially also the European) regulatory framework by extending and thus improving the existing balancing system for charging processes. The virtual grid approach is easy to integrate into the existing balancing system, as it is based upon it—comparable to the, e.g., traction current system or balancing between two grid operators. However, it is also easily transferable to all other EU countries, as they have a balancing system that is comparable to Germany's in the main points. In this respect, the EU makes hardly any particular specifications. A European rollout is, therefore, possible. Specifically, a coupling or interoperability of the platforms of the company Elia (EnergyBlocks) and BANULA is already being considered. Elia is very interested in the results of the BANULA project since both concepts are based on a virtual grid area. The company Elektromaps from Spain, which provides information about charging points throughout Europe, has expressed interest in participating in the project.

In a further step, BANULA will be presented by TransnetBW and 50Hertz in entso-e in the context of the established TSO-DSO cooperation. Currently, the managing director of TransnetBW is chairman of the working group for coordinated cooperation with the new European DSO association "EUDE". This provides the best conditions for coordinating processes between the two associations throughout Europe with regard to a virtual grid area. Against this backdrop, on the one hand, we carry the concepts to Europe, and on the other hand, we also want to actively accompany European developments (e.g., FlexHub, Equigy) in order to derive possible synergies for BANULA.

In summary, the technology is thus transferable to other countries. On the operator side, the Schwarz Group is a project partner that operates many hundreds of charging points not only in Germany, but across many other European countries. It is interested in a solution for all of its charging points, so it also has a great intrinsic interest in developing an international solution.

5. Results and Practical Applications

To prove and validate the project's underlying concepts, a pilot of the entire system and all players involved is implemented. For each role mentioned above, there is at least one organization necessary to adapt and implement the idea to make the ecosystem applicable in the current German energy market. Therefore, the project is composed of a multitude of entities in order to be capable of proving the concept end-to-end. As the approach of the system shall eventually be rolled out in the real world's energy market, the pilot is applied to the infrastructure of two large German charging networks and not only in a laboratory setup. For this reason, the new ecosystem is based on the current German and European regulations of the energy and e-mobility market. In the German energy market, a voluntary regulation system for CPOs to create a transaction-based energy balancing group was implemented in 2020 (BK6-20-160 [27]); however, it is not widely used by CPOs in Germany due to the lack of adequate incentives. For the pilot project, this regulation system is analyzed, the flaws are exposed and practicable improvements are made. Hence, the pilot project focuses especially on improvements, which create benefits for the CPOs to participate in this voluntary regulation system but also integrate into the current technical market solutions. Furthermore, the new ecosystem shall include the application of bidirectional charging and decrease the administrative burden as charge points—in Germany—so far are not considered as energy market locations but as energy metering locations.

To fulfil the ecosystem's transparency objectives, the pilot project evaluates the usage of distributed ledger technologies and implements the best fitting solution into the pilot implementation. Therefore, the pilot will be split into multiple implementation and testing stages. In the first stage a prototype—the minimal viable product (MVP)—is implemented and tested. Therefore, the technical feasibility of the project is shown by implementing the necessary roles for a limited set of use cases and charging stations. For this approach only the least features of the roadmap are implemented and tested in a friendly environment with known drivers, CPOs, EMPs, grid operators and—if necessary—shadow balancing. Thus, we can implement and test the MVP, even if the current regulations are not fully satisfied. The roadshow across Germany—from Freiburg to Berlin—shall demonstrate the crossregional approach across the four balancing zones operated by the German TSOs.

The use cases to be demonstrated in this roadshow—shown in Figure 5—cover the most important roles for the combination of the e-mobility ecosystem and the energy market ecosystem. The goal of the roadshow is to enable system- and grid-compatible charging at any charging point. In the roadshow, two electric vehicles with charging cards from two different EMPs will start the journey from Freiburg to Berlin. They will charge simultaneously, also at charging points of one and the same charging station, but authenticated through the different EMPs. The charging quantities will be allocated to the respective balancing group of the respective EMP and will appear in the correct balancing group bookings. The supplier of the physical grid connection point (to which the charging infrastructure is connected) will not change—however, the two selected EMPs will deliver the energy for the charging processes. After the MVP is realized and tested successfully, the next stage of the project with more users, charging stations and use cases will be implemented. For testing the ecosystem under real conditions in Germany, a large number of charging stations will be integrated into the BANULA ecosystem and the functionality will be proven and validated within a one-year fleet trial. These vehicles will be handed over to different groups of test subjects who differ in terms of their usage behaviour and the provided charging options. The results of the testing groups will form the basis for evaluating the application of the ecosystem to end users and improving the pilot project. In addition, a roadshow across Germany—from Freiburg to Berlin—will demonstrate the crossregional approach in the four balancing zones operated by the German TSOs.

During the lifetime of the pilot, a series of workshops with experts in the field of energy and mobility will be held and a new expert community will be founded. The feedback of the expert rounds will be integrated into the pilot and the interim results will be published to the community.

The entire pilot of the BANULA ecosystem is divided into multiple MVPs, the roadshow being one of them. Because the German energy market is highly regulated and the BANULA ecosystem demands that many players in the energy market adapt their software systems and processes, many perspectives need to be considered in the implementation of the entire pilot. Adapting the current German law [26] and following the BDEWs application documents [27] is not easy, as most of the current software systems and processes do not support them. In order to develop a functional pilot, all use cases of the BANULA ecosystem have been broken down into technical use cases—there are currently 24 of them—which were, in turn, grouped into several MVPs. Therefore, each MVP is a standalone part of the ecosystem, which addresses different technical and functional parts of the BANULA ecosystem.

The first MVP of the entire pilot and the basis of the entire ecosystem—the ability to charge with a different energy supplier than the energy supplier of the charging point and account for the energy amount to the correct energy balancing group—is implemented and tested at one location in one distribution grid in one transmission network. Simultaneously, the same processes and implementations are prepared at four other locations. All of these four locations are on different properties, while three of them are in new distribution grids and two of them are in new transmission networks.

Based on the experiences of implementing the BANULA ecosystem on different premises in different distribution networks in different transmission networks, each case has its own tasks to handle. Even as the law supports an innovative concept as the BANULA ecosystem, the software systems and processes of the current energy market players do not support a smooth implementation at every location at present.

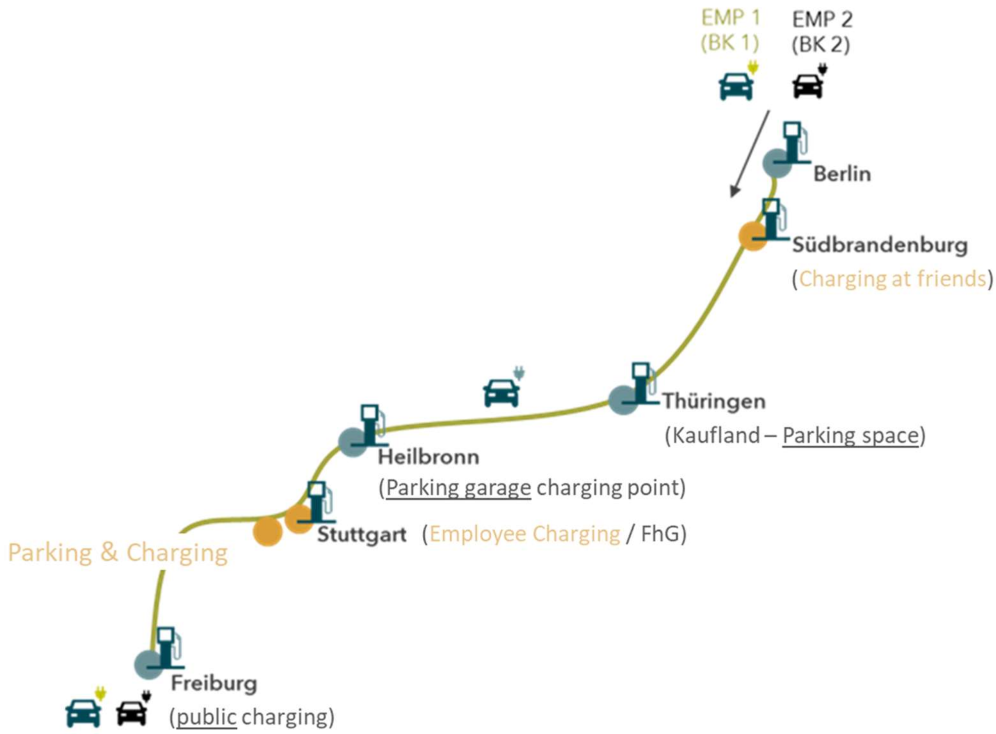

Figure 5. Overview of the planned roadshow across Germany—from Freiburg to Berlin—to demonstrate the MVPs important use case.

6. Discussion

The content of the BANULA concept is sufficiently complex and innovative that certain reflections and assumptions are certainly open to discussion. As discussed above, the added values for each role are, therefore, preliminary considerations and may change depending on what applies in practice. Questions such as the following arise: Does the transfer of responsibility for energy procurement from the role of CPO to the role of EMP actually lead to more reliable consumption forecasts and an associated increase in balancing group loyalty? Do users appreciate the new added value offered by the BANULA ecosystem to a sufficient extent to achieve market penetration? Is a new business model for CPOs that explicitly excludes energy procurement and sales attractive enough to prevail over the existing model? The topics of grid fees and ad hoc charging and how these can be integrated into BANULA are of particular interest. It is crucial that BANULA achieves a significant market share with CPOs and EMPs in order to realize the added values of the individual market roles, e.g., transparency regarding usability and prices (from the customer's perspective).

Of course, the ecosystem described in this document harbours risks as well as far-reaching opportunities, which can be outlined but not conclusively recorded. In any case, the use of the BANULA platform allows further added value to be realized beyond the basic idea of BANULA—think of dynamic prices or bidirectional billing, for example. However, the transaction costs are decisive for the profitability of these offers. For the BANULA platform to thrive as a vehicle for ecosystem transformation, proper governance is required. Therefore, the corporate structure must be well thought out, especially in view of the fact that the platform is a decentralized system.

7. Conclusions

With the concept of BANULA, a new innovative ecosystem for the operation and billing of charging processes is developed. The concept of BANULA offers added value for all market roles in the ecosystem and brings together energy economic processes, balancing charging energy quantities and the processes in electromobility. The benefits for selected stakeholders are as follows: End customers can choose their electricity supplier at BANULA charging points and are not bound to the supplier associated with the charging point; EMPs offer their electricity at all BANULA charging stations and develop new business and tariff models for their customers; CPOs (Charge Point Operators) can focus on operating the charging stations and delegate the procurement of the corresponding electricity quantities to the EMP and its suppliers; and distribution and transmission grid operators benefit from increased transparency in their respective electricity grids.

To achieve these objectives, BANULA defines new processes and roles, reassigns responsibilities and develops a technical backbone layer. The latter is based on blockchain technology (distributed ledger technology) and offers security, full transparency and auditable traceability. BANULA adopts a blockchain-based approach where the blockchain itself stores only a restricted amount of data. However, it serves as a real-time lookup table for each role within the system. To ensure data integrity and security, a comprehensive concept for roles and permissions will be developed to prevent data misuse. The described model is technically and procedurally operational within the current German legal framework. The feasibility will be demonstrated at selected charging stations.

An example of this is charging electric vehicles at public charging stations using the electricity generated from one's own photovoltaic system. To leverage added value at the European level, there are plans to transfer and adapt the entire system at the EU level.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

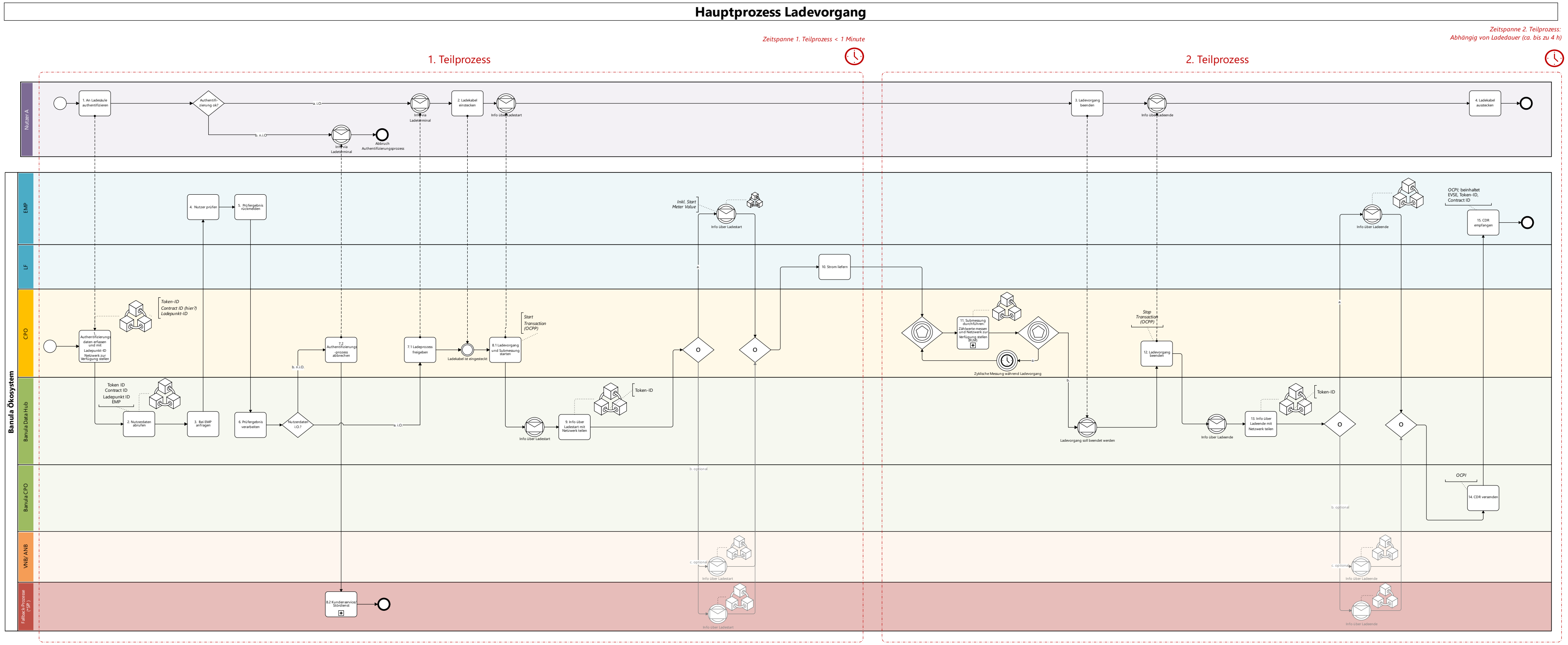

Figure A1. Display of the charging progress in the BANULA ecosystem as a swim-lane process diagram (BPMN 2.0).

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