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Review on Smart Charging of Electric Vehicles via Market-Based Incentives, Grid-Friendly and Grid-Compatible Measures

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Abstract: Smart charging of electric vehicles is a promising concept for solving the current challenges faced by connecting mobility and electricity within the context of the ongoing sustainable energy transition. It allows cost savings for the expansion and operation of the power grid and a more efficient use of renewable energies. However, wide implementation of smart charging requires further work on technical and regulatory issues and further development of standards, especially an end-to-end consistency of the control signals. A fully automated process, as well as customisable services and flexible tariffs, would also facilitate wider market penetration. The novelty of this paper is the consensus of German pilot projects funded within the German programme “Elektro-Mobil” on the communication channel between all stakeholders for the use cases of smart charging based on market price incentives. Within this consensus, the projects have illustrated how specific standards can facilitate the communication between smart charging stakeholders, become a reality in the pilot projects and should be applied to further use cases in the low-voltage network. This consensus results in a white paper. On this basis, the adjustment of the standards can be made to ensure the consistency of the control signals from the beginning of the control process up to the end. In an advanced Edition, solutions for the prioritisation and orchestration of the different control signals could be designed.

Keywords: regulation; smart charging; standardisation; V2G; V2H

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1. Introduction

The transition to electrically powered vehicles is associated with the goal of reducing the consumption of fossil resources and minimising emissions that contribute both locally and globally to the ongoing process of climate change. At the same time, the expansion of electric mobility poses new challenges to the existing power grid, especially with regard to the distribution grid level. For example, it increases the number of systems consuming electricity and thus the overall load demand. For this reason, the introduction of electric mobility will ultimately lead to a higher simultaneity of demand for electricity, and this is at a time when the fluctuating nature of the generation of renewable energy is increasing and exercising its own effects on the distribution grid. To address these challenges and to minimise the necessary investments in the power grid, smart charging concepts should be considered from the outset when expanding the charging infrastructure (e.g., [1,2]).

However, the implementation of smart charging faces some obstacles (e.g., [3,4]) that prevent a widespread roll-out of the technology, such as viable pricing models and market designs or a lack of continuity of control signals in the field of standardisation [5,6].

Therefore, this paper provides insights into necessary implementation options for smart charging from the perspective of German pilot projects and needs for action, as well as an overview of the state of the art regarding smart charging. The novelty of this paper is thus:

- The structuring work regarding the use cases of smart charging;
- The consensus of German pilot projects on the communication channel between all stakeholders for two specific use cases of smart charging;
- An agreement on the applicable standards;
- Solutions for prioritisation and orchestration of the control signals.

The projects of the funding programme "Elektro-Mobil" of the German Federal Ministry for Economic Affairs and Climate Action (BMWK) show in the context of their pilot projects that smart charging can be effectively implemented with the help of price and other control signals [7]. The projects of "Elektro-Mobil" have jointly published a study on smart charging, as well as a white paper, together with the accompanying research [7,8]. In the study, the authors outline concrete needs for action to promote or to implement smart charging via price signals. Several topics were identified, which are delineated in the following paper.

In addition, the accompanying research of the funding programme "Elektro-Mobil" moderated an agreement process on standards for the communication of the control signals to assure the continuity of the communication in all process steps. The results of this process were published in a white paper on the control of charging processes in electro-mobility [8] and are described in this paper as well.

This creates a basis for the next steps towards the roll-out of possible use cases on the market and for further work on the interoperability of the standards. For the implementation of smart charging, the transmission of the control signals must be ensured according to specific standards. Once there is consensus on the communication channels and the associated standards, the adjustment of standards can be made to ensure consistency of control signals from the beginning to the end of the control process. In addition, the implementation of regulations is required to enable stakeholders to complete the entire process from identifying market signals and grid challenges, through processing and orchestrating different control signals, to measuring and accounting for the delivered electricity.

This paper is based on a meta-study of existing technologies, structural ideas, standards, etc., and on a workshop-based consensus process.

The consensus process was led by the accompanying research of "Elektro-Mobil". The basis of the process was several expert workshops within the funding programme. In the first step, the participants agreed on a technical and regulatory framework in Germany that can be used as a basis for further work. In the second step, the participants created a map of communication channels for two specific use cases (one of which is shown in this paper). The next step led to a consensus on the combination of communication channels together with the associated standards. This consensus led to the joint publication of a white paper showing a solution for smart charging in the low-voltage grid for the specific situation in Germany. Industries can develop their products based on this knowledge of the surroundings and accelerate the adoption of smart charging.

2. Relevant Smart Charging: Use Cases and Learnings from Their Application in Different Pilot Projects

Smart charging can be understood in the two categories grid-friendly and grid-compatible charging. Grid-compatible charging offers several possibilities to integrate price incentives into charging management. Price-controlled charging is one way to realise a more efficient utilisation of the distribution grids and thus saving costs and freeing up resources that can be invested in grid expansion and balancing measures. Furthermore, it allows for adapted timing of electricity demand and the generation of renewable energy, as well as an active contribution to environmental and climate protection through the more efficient use of fluctuating renewable energies. In addition, this can create leeway for reducing the operating costs of the charging infrastructure.

For example, the charge point operator (CPO) can be motivated to reduce the price of the charged energy through lower grid connection costs.

The term price-controlled charging used in the following describes a charging management system that plans and implements the charging process of one or more electric vehicles (EVs) depending on price signals from the electricity market. In times of high electricity demand, charging the vehicle is delayed, and where bidirectional charging is possible, the EV feeds energy into the grid.

2.1. Use Cases

Smart charging is highly dependent on the specific use case. In the following, various use cases are presented, which include smart charging via price incentives and grid measures. Potentially, all use cases that include smart charging via price incentives or grid measures can be realised unidirectional and bidirectional.

2.1.1. Smart Charging via Price Incentives

The possibilities and characteristics of price-controlled charging are diverse. Table 1 classifies use cases of price-controlled charging with direct price control. Direct price control means that the charging strategy is adjusted exclusively on the basis of time-resolved price signals. In this case, the price signals can vary highly dynamically.

Table 1. Use cases of smart charging via price incentives ([7], Source: BDL project).

Use Case	Revenue Location	Customer Group	Regulation
Time arbitrage through trading on the electricity market (day ahead, intraday) (V2G)			In front of the metre
Tariff-optimised charging (stock market-oriented, variable grid charges) (V2H)			Behind the metre
Legend	 Grid and grid operator	 Industry/public use	 Home/private use

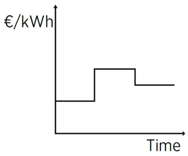
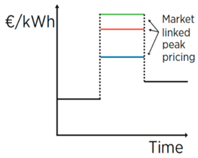
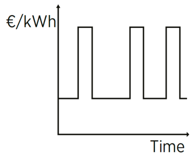
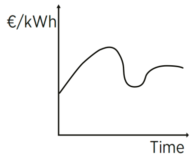
When using time arbitrage through trading on the electricity market, the charging process depends on the price differences of the intraday or day-ahead markets. The EV is charged at times when the electricity price is low. If bidirectional charging is possible, power is fed back into the grid when the price of electricity is high.

Tariff-optimised charging, in contrast, uses dynamic tariffs that are time-dependent. When the time is determined when the EV should reach the set battery level, the EV is additionally charged when the electricity tariff is low and the energy is fed back into the grid when the electricity price is high. In this use case, the revenue is not gained in the grid, but in the house.

Tariffs for price-controlled charging of EVs.

Similar to these different options for price-controlled charging, there are also different approaches to setting dynamic prices. Dynamic pricing refers to retail electricity prices that pass on at least some of the volatility of wholesale prices to end consumers. These marginal costs of electricity generation are expressed in the short run through spot prices and in the long run through forward prices. Dynamic pricing means that prices and price periods are aligned so that they actually provide incentives to shape energy consumption behaviour in line with wholesale price trends. According to Table 2, four types of tariffs can be classified.

Table 2. Smart charging based on price signals [9,10].

Type of Tariff	Time-of-Use Pricing (TOU)	Variable Peak Pricing (VPP)	Critical Peak Pricing (CPP)	Real-Time Pricing (RTP)
Setting prices	Static	Static and dynamic	Static and dynamic	Dynamic
Description	Usage over large time blocks of several hours (e.g., day and night pricing)	different periods for pricing are defined in advance, but the price for the on-peak period varies depending on market conditions	Rate in which electricity prices increase substantially for a few days in a year	Prices are determined close to real-time consumption of electricity on fine granularity (e.g., 15 min)
Graphical representation				

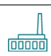
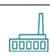
From a technical point of view, load profile measurement is required for the implementation of dynamic tariffs that follow the electricity market. This is the measurement process that the energy supplier uses at the customer's premises. This metering process has been used for decades for customers with registered load profile metering (RLM) and is to be introduced in Germany by so-called "smart metres" (intelligent metering systems, iMSys) for smaller consumers between 6 and 100 MWh per year of electricity demand on the distribution network level.

2.1.2. Grid-Friendly and Grid-Compatible Charging

The capability of price-controlled charging is not the only factor that influences the implementation of smart charging. Grid-serving measures also have a great impact on how smart charging is realised at home or at the workplace.

Table 3 presents three use cases in which grid-serving measures are used for indirect price-controlled charging. Indirect price control represents a charging strategy based on an overall optimisation that includes price signals.

Table 3. Use cases of smart charging via grid-friendly and grid-compatible charging ([7], Source: BDL project).

Use Case	Revenue Location	Customer Group	Regulation
Peak load capping (V2B)			Behind the metre
Increase in self-consumption (V2H)			Behind the metre
System services (V2G)			In front of the metre
Legend	 Grid and grid operator	 Industry/public use	 Home/ private use

When realising peak load capping, e.g., in a company, the overall peak load is reduced by charging the EVs during times of reduced load. The vehicles can feed electricity into the system when consumption of other consumers is high.

Increase in self-consumption means charging an EV to temporarily store the surplus electricity produced by an electricity generator (e.g., solar panel). This use case is part of vehicle to home (V2H).

System services can be used to minimise electricity shortages when network bottlenecks occur. The vehicles are charged or uncharged based on signals by the distribution system operator (DSO). This use case is part of vehicle to grid (V2G).

2.2. Application of Use Cases

Pilot projects in the funding programme "Elektro-Mobil" of the BMWK.

The projects of the funding programme "Elektro-Mobil" of the BMWK demonstrate how smart charging can be implemented taking into account control signals. The projects use different solutions that address diverse use cases and different forms of potential implementations in Germany. The solutions range from charging at the workplace or in residential areas and on the properties of municipal companies to bidirectional charging in private homes [7].

The project BSR-Li-Flx deals, among other things, with solutions for price-controlled charging on the premises of municipal companies. It is based on developing a decentralised solution for an electricity customer with registered power measurement (RLM customer) in addition to the company's own energy management system and the existing measurement technology. The control is based on a 15 min timetable. The calculation of the reduced purchase price is based on the subsequent measurement of the flexibility services realised by the customer.

In the project LamA—Charging at Work, the focus is on the nationwide development of charging infrastructure at Fraunhofer Society locations. In the project, a platform architecture for intelligent load management is being developed, which can take into account various control signals, such as simulated price signals from the electricity exchange, user requirements, and other consumers. In this way, the charging management ensures a peak load management for all consumers on the company premises.

In the project ELBE, over 7000 charging points are being set up under the premise of avoiding grid expansion in the distribution network. It is implemented exemplarily in the form of a "minimum valuable product", which connects the charging infrastructure to the electricity grid via a direct interface. This project pragmatically shows how the implementation can be carried out taking into account business models that have already been established in a similar form in the USA. In this project, the communication standard openADR 2.0 is used to connect the CPO to the distribution grid operator (DSO) or other entities, which has meanwhile been transferred to the IEC standard 62746-10-1 ED1.

In addition to the examples mentioned above, "Elektro-Mobil" has funded further projects that deal with smart charging in different use cases. Projects such as ARNi, BDL, DatenTanken, Resigent and unIT-e^2 are working on unidirectional and bidirectional smart charging, including a working standardised charging system. All these projects were involved in the consensus process to develop the above-mentioned white paper.

Further market application of price-controlled charging.

When smart metering is available, more and more companies offer variable energy prices for households or companies for different applications and initial situations, not only for charging EVs. A solution for time-variable grid tariffs has been developed under the leadership of the distribution grid operator MitNetz in Germany. The energy management system of a property or a smart wallbox controls the charging processes of the vehicles based on price signals (based on time-variable grid charges) as well as on information about available grid capacity, received from the DSO via an interface. There is no direct intervention by the DSO in this approach. Instead, the DSO uses the specification of the time-variable grid tariffs of the load management as a control instrument. With these instruments, critical grid situations can be prevented. The German company Easy Smart Grid, for example, has implemented a so-called Walrasian auctioneer in the pilot project SoLAR [11], which ensures that the local real-time price always reflects the balance of supply and demand. Unlike traditional markets such as EPEX, this means that participants are actively involved in price formation. Other companies, such as Awattar from Austria or Tibber from Germany, offer flexible tariffs where electricity is purchased cheaply on the stock exchange and the price is passed on to the customer. Most of them promote the use of renewable energy with their flexible tariffs. In addition, Tibber also provides a public Application Programming Interface (API), which can be used independently for integrating applications or for smart home control. The company Stromdao offers a variable tariff throughout Germany based on a green electricity index to ensure a low carbon footprint for its customers [12–14].

Even though there are already some variable electricity tariffs where lower purchase prices are passed on to the customer, the technical and legal implementation of the entire process is not yet feasible in Germany. The integration of the tariffs into the control of the vehicle's charging profile is also not directly offered by these companies, as most of them do not distinguish between different end-user equipment, such as EVs or heat pumps. In domestic use, this can be implemented via the energy management system (EMS) of a property or alternatively via the CPO backend, although the realisation of both solutions is still very complex for private households.

International experiences with price-controlled charging.

Worldwide, most experience has been gathered using dedicated static time-of-use (TOU) charging for EVs [15]. This model is currently offered in California by Pacific Gas & Electric (PG&E) [16] and by San Diego Gas & Electric (SDG&E) [17]. Both provide different TOU tariffs from which the customers can choose depending on their individual energy profile. They define peak hours, in which the consumption of electricity is more expensive than in off-peak hours. A project with a critical peak pricing (CPP) tariff was launched in France [18], where the price increases significantly for a determined period of time that is communicated in advance. If consumers shift their electricity use to off-peak hours (outside this time frame), they receive a fixed cost reimbursement [19].

Other pilot projects were launched to implement dynamic pricing for EVs, such as SDG&E, which offers three different tariffs for EVs at home with off-peak and "super off-peak" rates. These depend on the time of year and day [20]. Another pilot project to introduce dynamic pricing was started in Norway in 2019 by the Norwegian Water Resources and Energy Directorate (NVE) [21]. The charged tariff depends on the electricity demand in a given period, which provides a direct incentive to avoid EV charging during peak hours.

Comparison of first solutions.

Static TOU was found to be easier to realise and easier to understand. With the exception of the standard tariff, TOU is the most common pricing model, even though acceptance and adaption have to be increased by further incentives [22]. However, optimal grid load and use of renewable energy can only be achieved by implementing dynamic control signals, as proposed by the "Elektro-Mobil"-projects. Although the introduction of real-time pricing (RTP) has already begun [19], much development is still necessary before dynamic pricing can be realised as a standard. The necessary developments depend on technical and regulatory issues, and the standards must be compatible. What is needed is both a fully automated process and customisable offers, which provide customers with flexible tariffs. Usually, the DSOs offer tariffs with mixed calculation on the supplier side, as well as offers for pilot projects with special conditions.

3. Consensus on Communication Channel and Standards for Price-Driven Use Cases

Building a system architecture that connects the charging infrastructure, the backend of the charging infrastructure, the energy management system and the preferences of EV users while at the same time controlling the charging processes based on grid- and market-oriented information is an extremely complex task. This complexity requires a large number of interfaces and standards.

Much work has already been conducted by the German standardisation committees. In 2021, ISO 15118 still lacked a comprehensive implementation of a standard in vehicles and charging infrastructures to ensure that information from battery management in the EV is passed on to the electric vehicle supply equipment (EVSE). This deficit is currently being addressed in an update of the standard ISO 15118-20. ISO 15118-20 is scheduled for publication in summer 2022. This updated version includes the deposit of the charging certificate in the EV and additional functions of the charging management that enable V2G [23].

ISO 15118-20 represents a significant step towards bidirectional charging on the section between EV and EVSE. However, further standards need to be established in support of bidirectional and smart charging. Furthermore, standards need to be linked to ensure the whole process of load control and billing. In consideration of the German framework described, e.g., by the National Platform Electro Mobility (NPM) [24], VDE FNN targets picture controllability of EVSE [25] and the smart metre gateway-Roadmap-process [26,27]. A range of projects funded within the funding programme "Elektro-Mobil" agreed on a series of standards to process the communication for smart charging. These standards can currently be used nationally and, to some degree, internationally [8]. The work of the funded projects and the accompanying research support the process of standardisation by highlighting which configuration of standards facilitated the communication for two exemplary use cases of smart charging and recommending this configuration for further use cases. The core configuration is a triad consisting of the standards ISO 15118, IEC 63110 with OCPP and VDE-AR-E 2829-6 (equality to VDE-AR-E 2122-1000 in process) with EEBUS among others. Figure 1 shows the actors/entities and the communication channels of smart charging systems for two specific use cases that occur in the "Elektro-Mobil" pilot projects. While the upper graphic in Figure 1 shows the communication channels for price-driven use cases, the lower graphic depicts the communication channels of emergency regulations via grid measures. In addition to the different communication channels in the respective use cases, Figure 1 also shows the relevance of different standards depending on the use case.

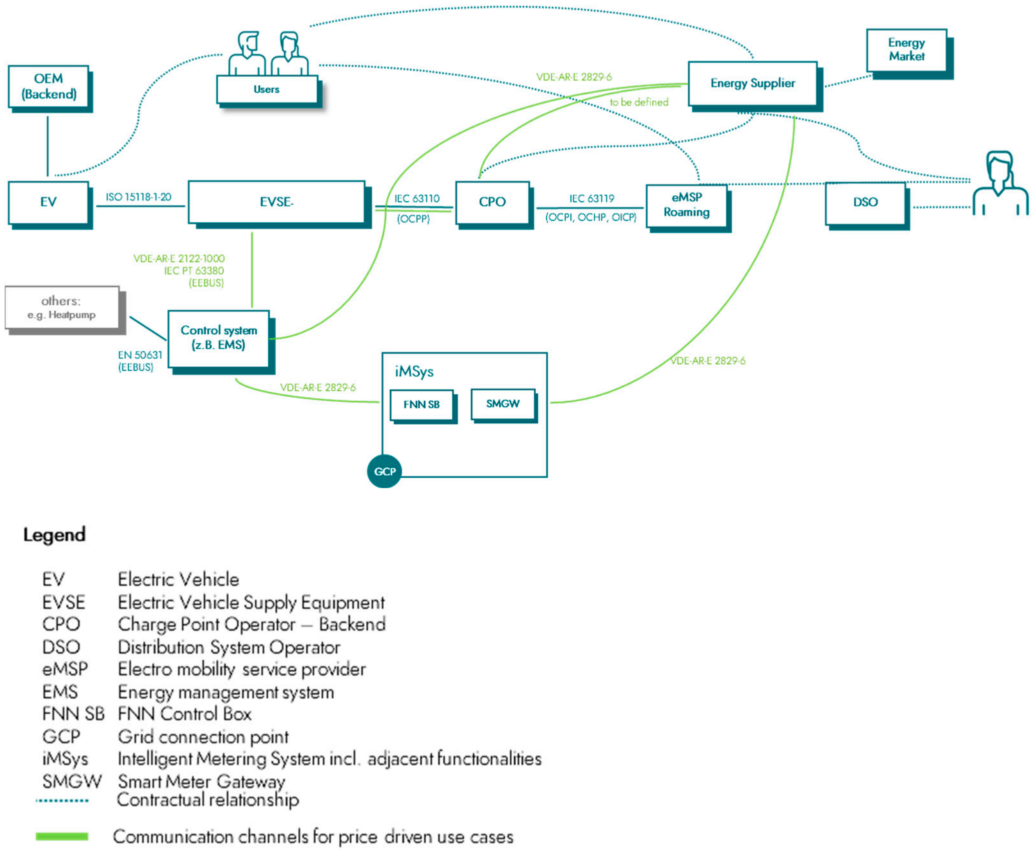


Figure 1. Smart charging system. Communication channels for price-driven use cases (green-coloured lines, upper graphic) and of emergency regulations via grid measures (red-coloured lines, lower graphic). In addition to the different communication channels in the respective use cases, the relevance of different standards depending on the use case is also shown.

In order to provide solutions for different use cases and situations, the projects are working on different approaches. Most projects are developing solutions with local control at the grid connection point. The project ELBE is pursuing a cloud-based approach to implement smart charging and uses openADR for the connection to the DSO. Both figures show the complexity of smart charging and its standards, which most projects have been able to agree on. The "Elektro-Mobil" projects have made it possible to agree on the standards concerning smart charging via price incentives and grid measures.

In an expanded version of the aforementioned white paper [28], the accompanying research and the "Elektro-Mobil" projects have incorporated supplementary proposals for prioritising and orchestrating control signals and control in general via a digital grid connection point. Via a power limitation at the (digital) grid connection point (below which the customer system can act freely) and an orchestration of the systems (through predefined prioritisation levels of control signals) via an energy management system behind the grid connection point, market use cases (for controlling the charging processes) can quickly be developed further. This reduces the complexity of the overall system. It can be accompanied by simple coordination, which makes it possible to prioritise and process the control signals and their sometimes conflicting nature. In this way, the ramp-up of electromobility, including grid integration, can be advanced without endangering grid stability in the distribution grid, and at the same time contribute to grid support and system security at the levels above. VDE FNN published an impulse paper on this topic in July 2022, which launched a stakeholder consultation process. The feedback will be incorporated into a subsequent key points paper on future grid operation with flexibilities in the low voltage in 2023 [29]. In addition, the expanded version of the white paper also addresses possible approaches to a resilient design of the charging infrastructure system (e.g., through the automated continuation of stand-alone operation and black start capability) [30,31].

Based on this consensus, further developments were possible in other areas such as compatibility. To achieve a standardised system that functions on an international level, further work is needed to develop new standards and to update existing standards.

In addition, the implementation of regulations is necessary to enable stakeholders to fulfil the entire process from identifying market signals and grid challenges to processing and orchestrating different control signals, measuring and accounting for the delivered electricity.

4. Potentials, Incentives and Needs for Actions for Smart Charging

4.1. Economic Aspects

As a result of the activities of the funding programme "Elektro-Mobil", relevant needs for action to promote or to implement smart charging via price signals were derived in various topic areas outlined below. At the same time, a consensus was reached between the funded projects on standards regarding the communication for smart charging under the German legal framework for specific use cases [8].

To create an economically functioning system for smart charging, there are different aspects to be considered. The following sections will focus on exemplary aspects.

"The integration of EV charging in a smart and connected environment will be a key success factor, enabling annual revenue growth of up to EUR 5 billion in Europe by 2030. A reliable and intelligent charging infrastructure is the key for the mass transition to electric mobility", states consultancy firm P3 [32].

The full potential of EVs for the energy system is realised when they are intelligently charged and also feed electricity back into the grid. In the future, electricity will be temporarily stored in the car and fed back into the grid at a later time. This will help avoid having to throttle the generation of renewable energy. EVs capable of bidirectional charging will make an important contribution to the stability of the electricity grids. The electricity fed back into the grid can be used as large-scale storage by pooling vehicles. A legal framework must be created to ensure that both grid integration and the flexible use of smart and bidirectional charging succeed at all grid levels. Finally, EV owners will only make their mobile storage available for flexibility services if they can generate income from it and thus reduce their total cost of ownership. The investment costs for all participants in the business model of bidirectional charging (vehicle users, aggregators, charging point operators) will only be refinanced on the market if the necessary investment costs can be recovered through corresponding profits.

4.2. Raising Ecological Potentials Economically

In addition to measures to control charging processes, pooled storage of bidirectional vehicles can make an important contribution to reducing investments in grid expansion, ensuring grid stability, guaranteeing supply security and increasing the share of renewable energies in the power system. Bidirectional charging will limit the need for investments in gas power plants by up to EUR 25 billion by 2050. Load procurement costs on the European stock market could be reduced by EUR 45 billion per year in 2050. In the scenario of bidirectional charging, the average European price of electricity falls by 3 EUR/MWh, and the European system costs will be reduced by a total of EUR 9 billion per year in 2030 [33].

As shown in [34], smart charging of EVs can also have positive effects on household electricity prices, grid load and emissions in Germany. With more EVs in use, the overall demand for electricity increases. Uncontrolled charging of EVs will cause load peaks, because most of these vehicles are charged at home after work when household consumption is high. Controlled charging can help flatten the load curve by shifting the charging process to night hours. Hence, the need for grid expansion is reduced despite the overall increase in demand for electricity. This improves the general grid load. Network charges, which can be described as a temporary rent of the grid network, are reduced due to the more efficient use of the grid. However, more research is needed to determine whether the demonstrated cost differences between smart and non-controlled charging are sufficient incentives to nudge EV owners to participate in charging management. To leverage these positive effects, the regulatory framework needs to be adapted in such a way that the ecological incentives are also reflected in monetary terms for the implementing persons or actors [21]. Another, even higher incentive can be created by implementing bidirectional charging, which can reduce the pressure on the grid even further.

The integration of economic or control signals into the charging management is mandatory for the implementation of smart charging. With no standards existing for this important interface yet, the integration of signals is currently the most urgent need for action, especially for smart charging. In consequence, generally accepted standards are necessary to simplify access and use of economic signals for charging management. The achievements of the funded pilot projects on standardisation are highlighted in Section 3.

4.3. Creation of Incentives, Regulation and Use Aspects

When designing incentives for smart charging, two different target groups must be taken into consideration—commercial addresses and private drivers of an EV. It is of primary importance that users from both target groups receive financial compensation. Also important, though secondary, is their contribution to the turnaround in energy policy, as well as their impact on grid stability. The users' choice of the charging management system depends highly on their personal and economic preferences (e.g., [3,7,35]). If a private person is generally interested in environmental protection, they will usually select more eco-friendly tariff models. Companies are increasingly forced by customers to reduce their carbon footprint. Further non-financial incentives—especially for private customers—could be created by installing appealing user interfaces, e.g., in the form of app-based feedback on the individual contribution to climate protection (gamification). For drivers of EVs in particular, other less obvious motivators, such as a positive user experience and the assumption of a pioneering role in society are relevant for the use of intelligent charging systems [7,36].

The access to price signals and the amount of financial leverage differ between private households, small companies and companies with high energy consumption and individual contracts, so-called "customers with registered power measurement" (CRPM). Compared to small energy customers, customers with registered power measurement have an easier starting position for the introduction of price-controlled charging management due to the already existing measurement technology and the 'individualisable' contract design. For these customers, the current possibilities to use price signals from the electricity market and the grid for charging management are currently shaped less by technical factors, but more by organisational and contractual factors, such as contracts that include peak load shaving and respective capping on a large scale.

Data privacy, data availability and data economy need to be ensured for all business models. Smart charging requires data to optimise the charging process, which must be provided or exchanged in particular by users, CPOs and electro-mobility service providers (eMSPs). It must be ensured that the data are provided by the respective players and that data protection and the principle of data economy are observed for the critical infrastructure of charging points.

Creating attractive incentives is not only a question of business models. It is also a question of regulation to enable envisaged developments. Particularly in view of the fact that in Germany taxes and grid fees account for 70% of the total price of household electricity [37], a variable electricity exchange price would only have a very limited financial incentive effect on the charging behaviour under the current legislation. In other countries such as the USA, more attractive price incentives could be achieved due to the different market and regulatory frameworks that prevail there [7]. In consequence, it must be clarified how a higher incentive can be achieved via regulatory intervention and how regulatory measures can be effectively used to push controlled loading. It should also be identified how the incentive system can be designed most efficiently for the desired goals and thus achieve the greatest effect. This could mean, for example, that the focus is not concentrated solely on reduced prices for off-peak periods. Static price components could be used as well—for example, reducing the building cost contribution with stipulated controlled charging. Here, the incentive would lie in the reduction of the initial investment and not in the ongoing operation and would directly allow a lower connected load to be realised. The business segment of smart charging is already seen as central by relevant actors and is considered to be a significant source of revenue. An important question in this respect is how a critical mass of flexibilities, which is traded on the electricity market, can be provided by electric mobility. The bundling of flexibilities could help incentivise stakeholders or aggregators to invest, despite the high costs of hardware and software, as well as the ongoing operating costs that have to be covered. Regulations need to be adapted accordingly based on the knowledge of user behaviour, depending on differences between private and commercial customers [7,33].

5. Conclusions and Outlook

Smart charging can help remove the barriers that currently hinder the expansion of electric mobility. It could potentially reduce costs for users while simultaneously improving the stability of the grid. At the same time, a higher share of renewable energy could be fed into the grid, and investments in grid infrastructure could be reduced. However, smart charging is currently not yet prevalent. Various projects in Germany, the USA and in other European countries are researching how it can be optimally implemented. In some countries, implementation is already partially possible. It was found that the most user-friendly smart charging tariff is TOU, which offers reduced electricity prices during off-peak hours and is already in use in several regions of the world. Nevertheless, it is possible that more efficient tariffs for the grid, such as dynamic RTP, could assert themselves if the charging process is conducted automatically. It is crucial for smart charging that relevant standards for the communication between all entities are compatible in order to guarantee the processing of the entire chain from load control to billing. In Germany, the most promising seems to be the core configuration of standards consisting of ISO 15118, IEC 63110, with OCPP and VDE-AR-E 2829-6 (equivalence with VDE-AR-E 2122-1000 in process) among others, EEBUS between EV and EVSE and grid. Internationally, openADR is also a preferred standard for connection to the grid. While their usage can depend on the use case, it is also possible that their functionalities and contents need to be converged. For this reason, further observation is needed.

While smart charging already has many advantages, bidirectional charging offers even higher incentives for users and for the spread of electro-mobility in general, being more climate-friendly. With this system, it is not only possible for users to save money when charging their EVs during off-peak hours, but also to earn money by selling energy that had previously been stored in their vehicles during a period of oversupply. However, bidirectional charging does not only provide incentives for users, but could also play an important role by ensuring grid stability. With pooled bidirectional charging supplied as system services, renewable energy can be used to a greater extent due to the system's ability to compensate for the natural fluctuations in the production of this energy. Smart charging can thus help in paving the way for a more climate-friendly world and an efficient energy system. In order for the aggregated flow of electricity from EVs into the energy system to take place via V2G and V2H, all necessary processes must be clearly regulated by law.

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