World Electric Vehicle Journal

MDPI

Article

Innovation Needs for the Integration of Electric Vehicles into the Energy System

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Received: 11 October 2019; Accepted: 4 November 2019; Published: 12 November 2019

Abstract: The mitigation of climate change and the substitution of fossil energy sources is one of the greatest tasks of our time. Electric mobility is the most promising solution to decarbonize the transport sector. As the market for electric vehicles is quickly gaining momentum, an urgent need for an intelligent integration of the energy and mobility system arises. This integration leads to a multitude of technical, economic and social challenges. Through a validated road-mapping process, the needs for future research, development, standardisation and regulation have been identified and visualised. Recommendations for action for decision-makers in politics and industry have been derived from those innovation needs. In summary, the most promising innovation path is the consequent application of smart and flexible charging concepts as well as an adaption of the regulations and roles in combination with the consequent usage of renewable energies. In five to ten years, also synergies through the exploitation of autonomous electric vehicles will gain momentum.

Keywords: electric vehicle; energy; smart charging; smart grid; regulation; roadmap; recommendations

1. Introduction

The influence of human activities on climate system is clear and the observable climate change can largely be attributed to anthropogenic emissions of greenhouse gases [1]. The transport sector counts for 19.5% of the European Union greenhouse gas (GHG) emissions [2]. For Germany it is 18% based on the 2018 data [3]. Evolutionary improvements in vehicle technology and energy efficiency have been achieved ever since. This, however, did not result in a significant reduction of GHG emissions. Compared to the reference year 1990, GHG emissions from the transport sector increased by 2.2% in Germany [4] and by 28% in the EU [5]. This is mainly caused by a growing economic activity and increasing transport demands, and also due to the tendency towards heavier and stronger vehicles.

Upcoming regulations and objectives are starting to get more ambitious. In 2016, the German Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) published sector-based objectives for CO_2 emissions up to the year 2050. The German transport sector will reduce its CO_2 equivalent emissions by 45% to 95 Mt in 2030 [6]. In September 2019, a proposal for the national climate protection law was published to make those objectives binding [7]. The EU regulations on CO_2 emissions from new passenger cars (443/2009) and new light commercial vehicles (510/2011) are already setting average emission limits of 95 g CO_2/km by 2021 (new cars) and 147 g CO_2/km by 2020 for new vans [8]. In December 2018, the EU agreed on a further decrease of CO_2 emissions from new cars of 37.5% by 2030 compared to the 2021 levels, including an interim goal of minus 15% in 2025 [9]. These targets should translate into a 35% market share for electric vehicles (EV) and plug-in hybrids (PHEV) in the European car market by 2030 [10]. Figure 1 gives an overview of some of the most relevant objectives regarding the market share of electric vehicles. Several countries are aiming for a phase out of internal combustion engine (ICE) cars until 2030. Others follow in 2040. Germany experiences

a rapid market growth for EVs and aims at 1 million EVs on the road by 2022. This leads to the challenges to provide a widespread charging infrastructure and to always ensure the supply with low GHG electricity for vehicle charging purposes.

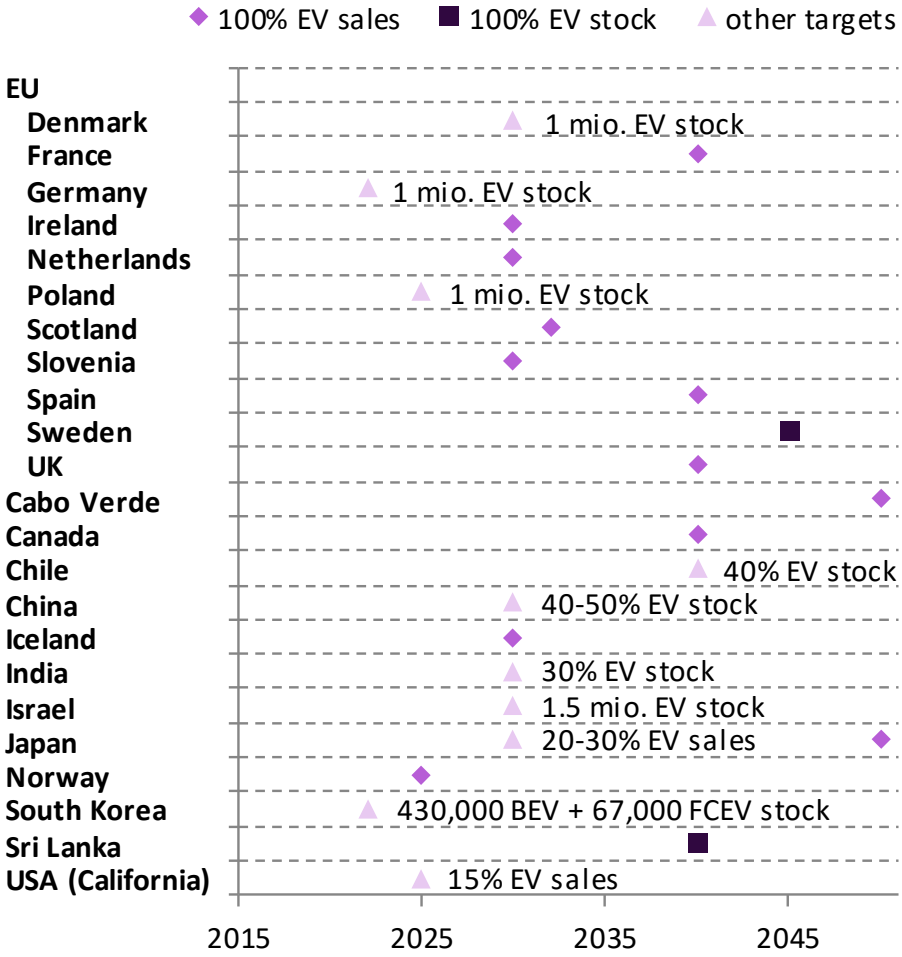

Figure 1. Political objectives in e-mobility, based on own research and [11].

In the spotlight of climate change mitigation policies, the energy sector faces the transition from fossil to renewable sources. In 2017, renewable energies accounted for more than two-thirds of the newly installed global electricity generation capacity [12]. Wind and solar energy are becoming the new major electricity generation technologies [12]. While reducing GHG emissions, these technologies are decentralized and show volatile energy generation patterns. The pioneers of this development are countries such as Denmark, Germany, Ireland, Spain, Portugal and some states of the United States, whose share of volatile renewables in power generation already exceeds 20% [13]. At the same time, new electricity consumers like electric vehicles, heating appliances or electrified industrial processes increase the volatility of the energy demand. Adding new electricity consumers also increases the average load. Electric vehicles, for example, approximately double the electricity demands of average households. This leads to the great challenge to always synchronize energy supply and demand both in time and in locality. Since renewable generation capacity as well as energy consumers are mostly connected to the distribution grid, an extension of electric grid capacity is needed. The aim to ensure security of electricity supply at minimal costs generates a demand for energy management and demand side integration solutions [14].

The integration of electric vehicles into the energy system needs innovative technical solutions in order to cope with the described challenges. This paper shows innovation paths and gives

recommendations for actions to enable coordinated climate change mitigation both in the transport and in the energy sector.

2. Materials and Methods

The aim of this paper is to characterize innovation needs to enable the integration of electric vehicles into the energy system and to derive recommendations for action for decision-makers in politics and industry. The chosen methodical approach is visualized in Figure 2. It is based on evaluations of literature and research databases. The findings have been validated by experts from the relevant subject areas. The study has been carried out as part of the accompanying research for the Federal Ministry for Economic Affairs and Energy (BMWi) funded programme 'ELEKTRO POWER II—Positionierung der Wertschöpfungskette' [15]. This study has been carried out with a special focus on German framework conditions. Because of the similarity of transport sectors throughout Europe, the results are partly transferable to other EU countries.

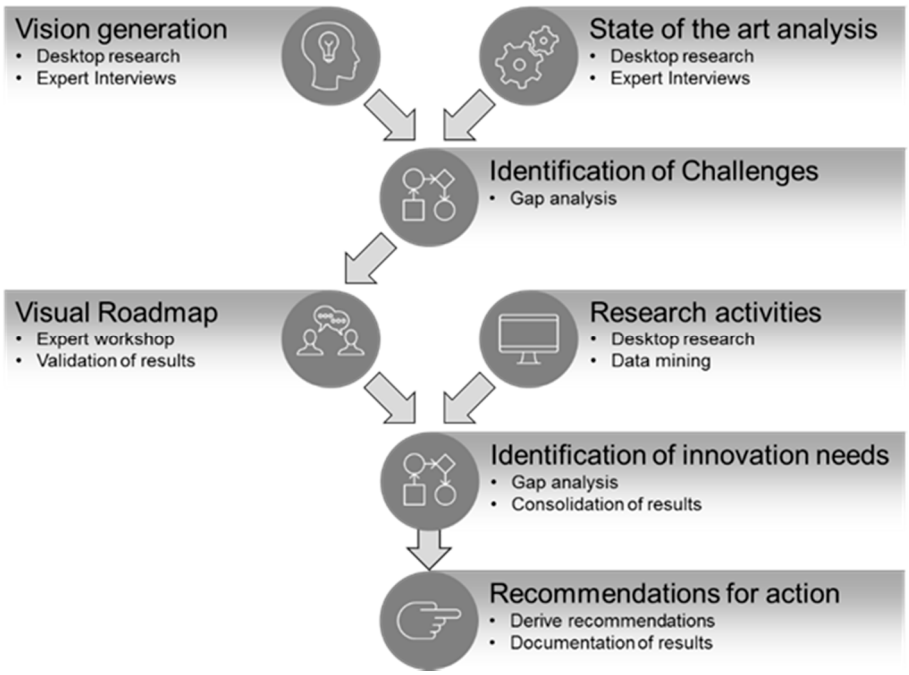

Figure 2. Applied methodology for the identification of innovation needs.

2.1. State of the Art

The first step is an assessment of the state-of-the-art in the integration of EVs into the energy system. A literature-driven desktop research has been carried out to determine the relevant technologies and their readiness level. To rapidly gain confidence in the results of this analysis, interviews with experts from the fields of electric mobility, charging infrastructure, vehicle to grid communication, smart grids and standardization have been conducted.

2.2. Vision

In the context of this study, a vision is a consistent description of a possible future. It was generated using scenario analysis methods [16]. Thus, a baseline scenario was generated for the integrated energy and mobility system in 15-years' time. The chosen time horizon is a compromise ensuring quality and relevance of the aspired results. It is long enough to allow the development of suitable innovation policies and short enough to estimate future developments with sufficient accuracy. It is based on an assessment of market dynamics, systems analysis studies and technology roadmaps. The resulting vision also incorporates the data on political targets given in the introduction.

2.3. Challenges

In a third step, this vision was then compared to the state-of-the-art in electric mobility and energy technology. A gap analysis was then carried out to identify obstacles in the path to achieve the vision. From these obstacles, the upcoming challenges were derived. In this context, a challenge describes a problem that may be solved by applying suitable policies. These challenges address the whole innovation process from framework conditions to key technologies, products and societal impacts.

2.4. Visual Roadmap

The relevance and completeness of these challenges were validated in an expert workshop. This workshop was held in April 2018, with 22 participants from science and the relevant industries. Amongst them, there were also participants from the ELEKTRO POWER II programme. Table 1 gives an overview of the composition of workshop participants. This workshop was used to discuss and validate the vision and challenges. On this basis and together with the experts, a visual roadmap has been developed. Visual road mapping is a highly interactive workshop format to include the knowledge of all participants. The resulting roadmap comprises success factors for the integration of the energy and mobility system. Furthermore, relations between these success factors have been analysed in order to identify the dependencies and synergies. In the framework of this study a success factor is a measure that aids to achieve the vision. A success factor can qualify as an innovation need, if it has not sufficiently been covered by past or ongoing research.

Table 1. Overview of the composition of workshop participants.

	Category (Number) of Participants			
	Research (7)	**Industry (9)**	**Consultancy (3)**	**Politics (3)**
Fields of expertise	Traffic and infrastructure management, charging services, energy system and electric grid modelling, energy storage	Small- and large-scale charging solutions, electric grid planning, energy trading, energy management software, technical inspection and metrology	Energy systems, electric vehicles, charging infrastructure development	Industrial policy, electric mobility, towns and municipalities

2.5. Research Activities

In order to identify innovation needs, the roadmap and the success factors need to be compared to the results of past and ongoing research activities. These research activities were mapped by analysing the scientific literature and by performing text mining on international research databases such as Förderkatalog (Germany) [17], CORDIS (EU) [18] or the NSF research spending and results database (USA) [19]. This analysis also includes activities of the German Federal Ministry for Economic Affairs and Energy (BMWi) which supported 13 research projects through its funding programme 'ELEKTRO POWER II: Elektromobilität—Positionierung der Wertschöpfungskette' [15]. The focus lies on the integration of electric mobility into the energy system, the optimisation of the electric mobility value chain, the further development of inductive charging systems in publicly accessible areas and cross-cutting topics such as questions on legal, security and standardisation topics [20,21]. The chart in Figure 3 shows the individual projects and their contribution to the integration of electric mobility into the energy system. The analysis of research activities also includes an outlook on future funding activities.

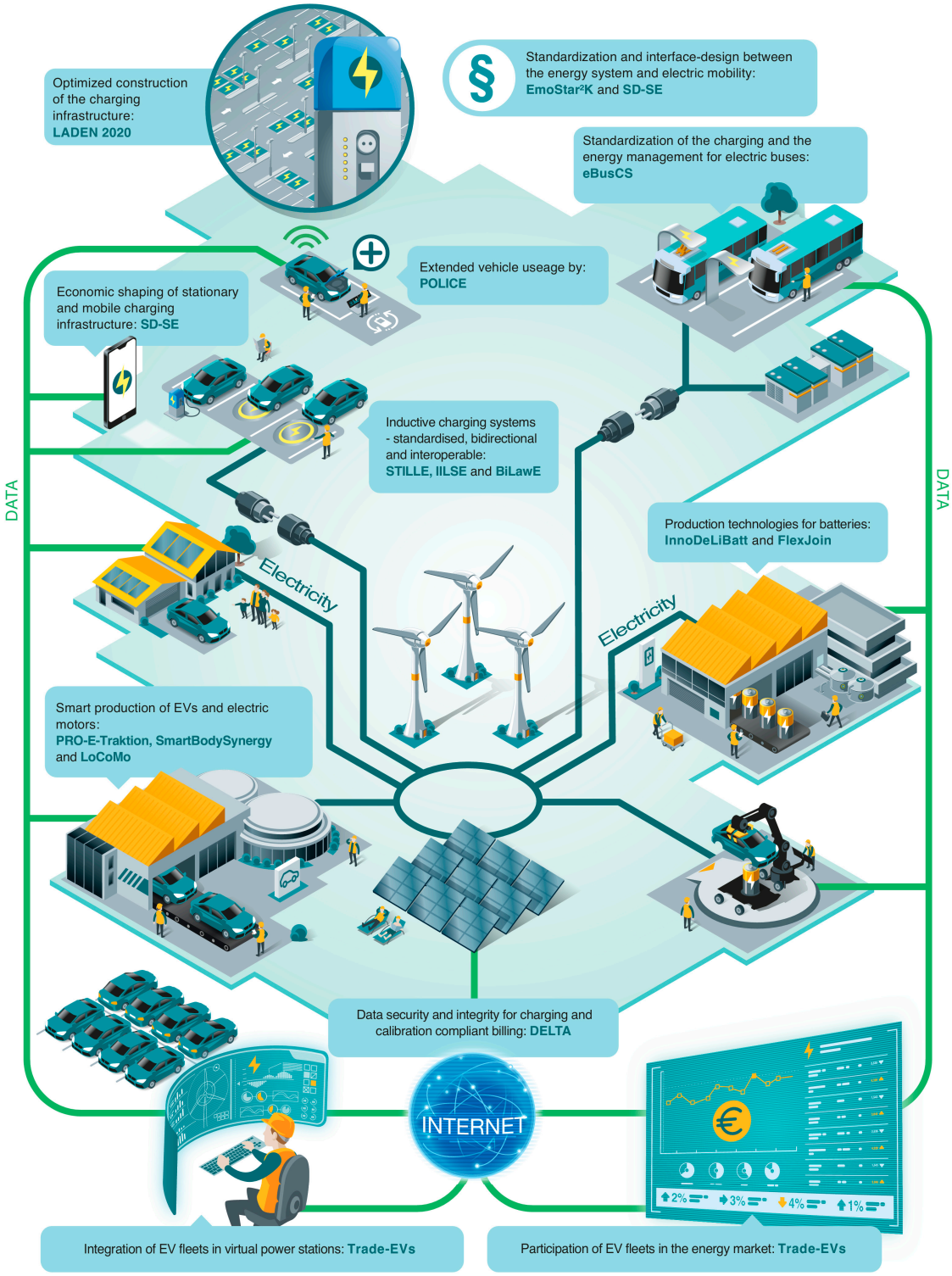

Figure 3. Innovations for electric mobility—ELEKTRO POWER II (© LHLK/Begleitforschung ELEKTRO POWER II) [21].

The BMWi will synchronise the recently started charging infrastructure projects in the 'Sofortprogramm Saubere Luft' [22] with activities regarding the roadmap 'Standardisation strategy for cross-sector digitisation in accordance with the Act on the Digitisation of the Energy Transition' [23] and the 'Barometer Digitisation of the Energy Transition' [24]. The objective is to achieve a further elaboration and consolidation of grid capacity compatible charging methods, the legal framework

as well as on standardisation and security topics. To support the market uptake of battery electric vehicles, Germany participates in the Important Project of Common European Interest (IPCEI) on battery manufacturing [25]. These activities together with the results from the database analysis deliver a broad overview of the ongoing and past research activities.

2.6. Innovation Needs

Innovation needs that so far have not been covered by the results of research activities are then determined by performing a gap analysis comparing the results of the roadmap to the screening of research activities. The identified innovation needs to deliver the knowledge basis for future actions regarding the integration of EVs into the energy system.

2.7. Recommondation for Action

In the final step, recommendations for action were derived from the identified innovation needs. These recommendations are addressed to decision-makers in politics and industry in order to enable an optimised use of resources. The derived recommendations shall enable the implementation of measures to achieve the vision.

3. Results

The main results are the recommendations for action derived from literature and expert knowledge following the described methodology. Results are given for the relevant steps of the evaluation shown in Figure 2, to provide a transparent overview of the knowledge basis that lead to the recommendations for action.

3.1. State-of-the-Art

Electric vehicles are widely seen as a more climate friendly alternative to internal combustion engine vehicles (ICEV). Several studies demonstrate that even with today's average CO_2 emissions from electricity generation of 440 g/kWh in Germany and 296 g/kWh in the EU in 2016 [26], EVs are showing an advantageous climate balance [27,28]. An evaluation by the German Federal Ministry of the Environment, Nature Conservation and Nuclear Safety (BMU) shows an advantage between 16% and 27% of the CO_2 emissions per kilometre over the entire vehicle lifecycle in Germany based on the 2017 data [29]. However, EV charging strategies have a significant impact on the CO_2 emissions. Thus, the ecological advantage of EVs over ICEVs is debatable under the current German framework conditions [30]. Along the progressing decarbonisation of electricity generation, the advantage of EVs over ICEVs is expected to grow to 32% and 40% in 2025 based on the improving energy mix [29].

Over the past decade EV technology has matured. Global EV sales are growing rapidly showing a two-digit growth in major markets. In 2018, China has become the largest market with 1,078,000 EVs sold, while Norway is the most mature market with a 46% share of EVs in the car market [11]. The global average market share of EVs has been 2.3% in 2018 [11]. Overall, the global stock of EVs surpassed the 5.1 million in 2018 [11].

Germany experienced a rapid market growth with 67,500 EV sales and a market share of 2% in 2018 [11]. In addition to that, the public charging infrastructure has grown. Until 2019, the German Federal Ministry of Transport and Digital Infrastructure (BMVI) has funded the installation of about 17,000 public charging points [31]. In most cases, effects on the electric grid are still neglectable. Nevertheless, several R&D projects are investigating the effects of high EV penetration on the electric grid. First products are entering the market, which optimise the vehicle charging in order to minimise the electric power demand while guaranteeing the availability of the EV.3.2 Vision

Extrapolating from the status quo, the following vision for the integration of EVs into the energy system was created. In future, road mobility will be provided by electric vehicles while exceeding the level of comfort of internal combustion engine vehicles. Through intelligent energy management, EVs will contribute to the transition of the energy system towards a fully renewable energy supply.

This qualitative vision is refined with quantified expectations to create a baseline scenario for Germany in the year 2035. The scenario is used to improve the understanding of the vision. It is determined by the following indicators:

- The share of electric vehicles in total vehicles sales is estimated at 60%.
- The share of electric vehicles in total vehicle stock is estimated at 25%.
- The share of renewable energies in energy generation is estimated at 60%.
- The total additional electricity demand from EVs is estimated at 26 TWh/a.
- The number of installed charging points is estimated at about 1.2 million.

This scenario can be classified as an optimistic but realistic vision. It describes a path that considers both promoting and blocking factors. The given quantitative indicators are derived from an analytic spreadsheet model based on literature data. The main assumptions are a constant projection of vehicle stock (47.1 million vehicles [32]), new vehicle registrations (3.5 million vehicles/a [33]) and mileage (13,500 km/a [34]). Further assumptions and rationales are discussed in the following sections addressing each of the scenario defining the indicators.

3.1.1. EV Market Share

The future development of the vehicle market has been researched in numerous articles. Figure 4 shows the result of a meta-analysis on the market development projections for EVs. It shows that uncertainty is still high. Four market diffusion paths for EVs have been identified ranging from a renaissance of the ICE in the extremely conservative path to an extremely progressive path that allows to meet the goals of the Paris agreement [35] to keep global warming well below 2 K.

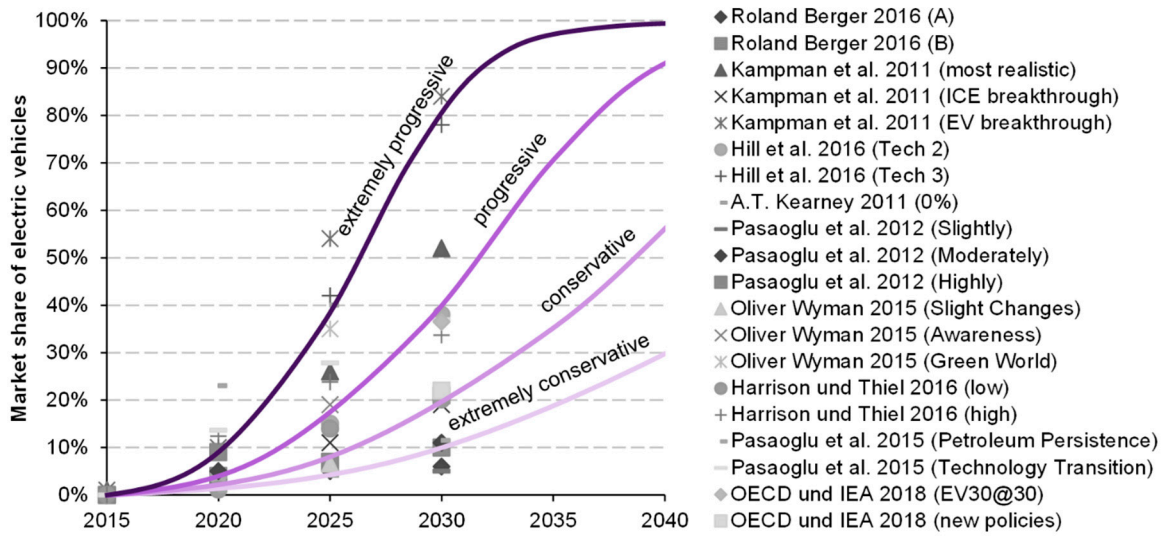

Figure 4. Projection of the electric vehicles (EV) market development until 2030 based on [11,36–43]

A moderate approach (progressive path) aiming at an 80% reduction of greenhouse gas (GHG) emissions until 2050, still requires the market share of electric cars to approach 40% by 2030. The political objectives of most countries shown in Figure 1 are above the progressive or even the extremely progressive curves. As listed in Figure 1, countries like Norway, Ireland, Slovenia, and the Netherlands have set political goals to reach a 100% EV market share by 2030 [11]. France and the UK are following by 2040 [11]. A rising number of electric vehicles available on the market reflects these goals. The assumption of a 60% share of EVs in total vehicle sales by 2035 in Germany lags a little behind the progressive path. This reflects Germany's ambition to become the leading provider of EVs [44] while also considering the persistence effects generated by a large number of jobs bound to ICEs.

3.1.2. EV Stock

Following the market diffusion path leading to a market share of 60% for EVs would lead to 12 million EVs in stock by 2035. This resembles a share of EVs of 25% in total vehicle stock with the exception of trucks and other heavy-duty vehicles, given that the total number of vehicles and sales figures keep at a stable level.

3.1.3. Renewable Energy Share

The share of renewable energies is of two-fold relevance for the integration of electric vehicles into the energy system. On the one hand, a rising share of renewable energies decreases the CO_2 intensity of electricity generation, which increases the positive effect of EVs regarding climate targets. On the other hand, a larger share of volatile renewables like wind and solar increases the necessity of demand side management. This affects the charging patterns of electric vehicles. The 60% share of renewable energies in electricity generation by 2035 in Germany is chosen in accordance with the current goal framework for the energy transition [45].

3.1.4. Additional Electricity Demand

To be able to determine the additional electricity demand, it is necessary to discuss the different electric drivetrain technologies. Beside battery-electric vehicles (BEV), further alternatives such as fuel cell electric vehicles (FCEV) and synthetic fuels need to be considered. Electricity can be converted into hydrogen or synthetic fuels to be used for mobility purposes. These technologies can have advantages over BEVs in terms of range, recharging time and usage of existing infrastructures. On the other hand, the acquisition costs are expected to be higher and energy efficiency is lower in comparison to BEV. For the same distance, a fuel cell electric vehicle (FCEV) requires more than twice as much primary energy as a BEV [46]. For synthetic fuels, approximately five times more energy needs to be generated [46]. In conclusion, a drive-technology mix for the transport sector is anticipated to be the most feasible path, with BEV in a central role, especially in cities. Alternative technologies will most probably be used for niche applications where battery-driven technologies are not as suitable. This is especially the case when high energy densities or long-range operation is needed. Considering these aspects, the additional electricity demand created by EVs is estimated at 26 TWh/a. This would correspond to a 4% increase in electricity generation compared to 2017 [47].

3.1.5. Charging Infrastructure

With BEVs accounting for the majority of EVs, a nationwide charging infrastructure is needed composed of mostly low-power chargers and few high-power chargers along the highways and in centres of urbanisation. Following the recommendation to install at least one charging point per 10 EVs [48] the total number of charging points is estimated at 1.2 million in Germany by 2035.

3.2. Challenges

A variety of challenges has been identified for the integration of EVs into the energy system by comparing the vision to the state-of-the-art in terms of a gap analysis. These challenges include technical issues, international regulations and standards as well as user behaviour and functioning business cases. To integrate a large share of EVs into the energy system the following challenges have to be solved:

- There is no clear long-term strategy for the energy transition in the transport sector.
- The installation of charging infrastructure needs to keep pace with the increase of EVs on the road.
- Many different actors need to be involved in the instalment of public charging infrastructure.
- The large number of different billing schemes for public charging confuse the electric vehicle drivers.
- Simultaneous charging of electric vehicles may exceed grid capacity and lead to outages.

- No standardised infrastructure for the communication between EVs and actors in the energy system (e.g., system operators) is in place. Furthermore, the German smart meter (SMGW) rollout is thoroughly delayed.
- There are few incentives to incentivise demand side management (DSM) of the charging infrastructure.

These challenges apply to German framework conditions but may be transferable to other countries as well. These challenges have been discussed during the workshop described in Section 2.4 in order to prepare the development of the roadmap. Subsequently more information and reasoning for the identified challenges is given.

In Germany and the majority of other countries, the current share of EVs rarely causes a major impact on the energy system [49]. However, the situation is changing, with more and higher-powered charging points being installed and a broader product range of EVs becoming available in the market. The potential influence on the electricity grid will increase. This sets a spotlight on distribution grids, where grid management mechanisms are far less sophisticated than in transport grids. Not only the overall electricity demand is going to rise, also the volatility in power demand could increase through uncontrolled simultaneous charging. This might lead to critical conditions with power peaks and fluctuations in the grid, which could result in costly emergency measures. Additionally, seasonal effects have to be considered for the energy system. Not only the electricity demand of EVs raises with lower ambient temperatures, also heat pumps and other applications in the heating sector have higher demands.

Countering these effects and to assure grid stability, extensions of the grid and a suitable charging management will be required. Power generation from renewable energies and power demand from the transport sector will need to be more closely aligned [46] both in region and in time. Studies are showing that with a working charging management a market penetration of EV of up to 30% should be achievable without the need for additional investments into the electricity grid [50]. So far, several factors are limiting the possibilities to manage charging. In particular, a considerable lack of data, information and prediction for the charging demand, as well as the unknown condition of the individual distribution grids are highlighted. Calibration compliant billing is still a hurdle, especially during DC charging [51].

EVs are typically charged immediately after being plugged in with the maximum available capacity and removed when fully charged or even before the full charge is reached. This does not leave a lot of room for grid stabilising energy management. For EV charging to be managed flexibly, vehicles need to be connected as long as possible and the energy management system needs to communicate with the grid control system. The ISO 15118 standard defines a communication interface for this purpose, but it still needs to be implemented both in vehicles and in the charging infrastructure. Furthermore, most vehicles and charge points are not yet prepared for bidirectional charging and other energy system services. International standardisation for charging and technological specifications still have to be implemented as well as a legal framework for flexible electricity prices to create incentives for grid beneficial charging [20,52].

3.3. Visual Roadmap

The major challenges in providing electric mobility at cheap costs, secure energy supply and a high level of comfort are broken down into solvable problems. On this basis, more than 20 experts from the mobility and energy sector were gathered for an interactive visual road-mapping workshop to validate findings and to derive success factors for the integration of the mobility and energy system. Only those success factors that are currently not sufficiently addressed by policies were selected to become part of the roadmap. The call for funding of public charging infrastructure investments, for example, was discarded because of availability of such funding ensuring a sufficient coverage of charging infrastructure [53]. The resulting roadmap is shown in Figure 5. Each box in the figure contains a success factor. High priority success factors identified by a selection process among the participants are highlighted by a darker background colour. Dependencies are visualised by solid

arrows while synergies are represented by dotted arrows. The road map is discussed in detail in the following sections approaching from the macro layer of overlaying innovation paths proceeding to the layer of individual success factors.

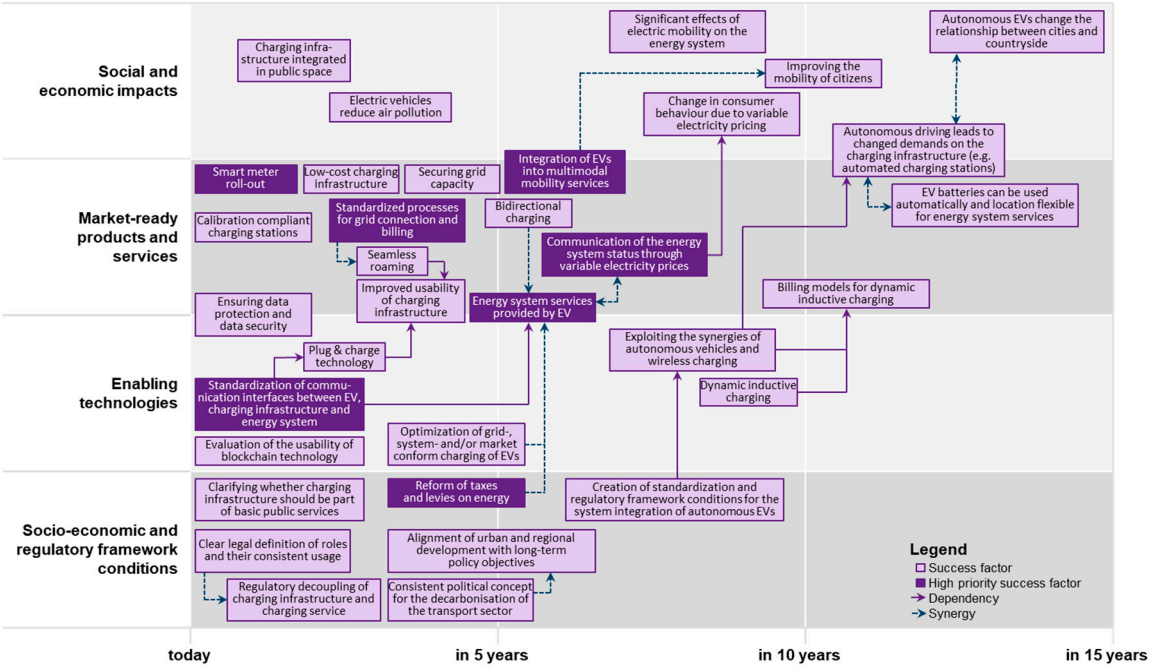

Figure 5. Technology roadmap for the integration of electric mobility into the energy system [20].

Two innovation paths for the integration of EVs into the energy system with high priority success factors crystallise from the visual roadmap shown in Figure 5. The first one addresses the built up of charging infrastructure and the integration of large amounts of EVs into the energy system. It starts by resolving pending standardisation questions and modifying the regulations in combination with the smart-meter rollout. This gives the ability to implement communication methods and business cases for flexible, integrated usage of the combined storage capacity of the growing amount of EVs. Most relevant is a reform of taxes and levies on energy to achieve the objectives. A reduction of fixed levies and taxes that only add a certain amount of money to the kWh of electricity, would enable dynamic electricity pricing. Thus, the availability of renewable energies could become visible to the end consumer through a price signal. This could lead to better energy management.

The second effect of reduced taxes and levies would be a decrease of EV operation expenditures making them more attractive to the consumer. Another important success factor addresses the need for a standardised communication infrastructure. With a suitable standard in place, R&D projects are required to implement it and to bring it into application. Utilising the standardised communication infrastructure in combination with dynamic electricity pricing and optimisation methods, EVs can be enabled to provide energy system services such as peak shaving and load shifting. This will also profit from a speed up of the smart meter rollout. In order to provide a seamless charging experience while using charging infrastructures operated by different companies, a standardised billing process is needed. Further standardisation (e.g., through one-stop-shops) is needed to streamline the process for the installation of new charging points.

A second innovation path addresses the effects of autonomous electric vehicles onto energy management. This path starts a few years from now and still requires a considerable amount of research on topics related to automated charging. Inductive charging is seen as a key technology to enable automated charging with autonomous vehicles. Solutions utilizing robot arms are still considered fragile and mechanically complex, which drives capital and operating expenditures. A high

degree of automation would significantly decrease the amount of charging points, as charged vehicles would not block necessary parking spaces in front of charging points.

Each innovation path is covering all four categories from 'socio-economic and regulatory framework conditions' and 'enabling technologies' to 'market-ready products and services' and 'social and economic impacts'. This marks the maturing of a technology from providing the societal basis over technology development and the market introduction of new products to impacts generated by a broad application of these products.

3.4. Recommendations for Action

For each of the four categories of the roadmap, various innovation needs have been identified from an analysis of research databases as well as utilising the results of a comprehensive meta-study [54] on this topic. The innovation needs translate into recommendations for action, which aim at turning the vision into reality. The necessary actions to achieve this goal are described below.

3.4.1. Improve Socio-Economic and Regulatory Framework Conditions

- Develop a long-term strategy for the energy transition in the transport sector to reduce risks for investment decisions and to enhance the market diffusion of electric vehicles. Reduced risks in future planning should lead to an accelerated market diffusion of EVs and to intensified R&D activities.
- Align urban and rural development with long-term policy objectives. This includes the rural population and strengthens the political backing for more ambitious climate and innovation policies.
- Create incentives for grid conform energy management of vehicle charging and the usage of electricity from renewable energies. This could happen through dynamic electricity pricing and reduced taxes and levies. Therefore, a reform of taxes and levies on energy consumption is necessary.

3.4.2. Develop Enabling Technologies

- Enhance and implement standardised communication interfaces between electric vehicles and charging infrastructure to enable plug&charge and vehicle to grid (v2g) functionality. Vehicle and equipment manufacturers need to implement a standardised solution to enable the provision of energy system services by EVs while ensuring a satisfying user experience. A corresponding standard has been developed with ISO 15118. Furthermore, the roles and the areas of responsibility for the different actors (e.g., vehicle and equipment manufacturers, electric system operators or charging point operators) need to be clarified.
- Development, testing and implementation of grid conform energy management for charging infrastructure. Government research funding should be provided for the development and testing of intelligent charging solutions. Real world labs are a suitable instrument to enable a fast and secure transfer of this research into industrial products. Existing funding mechanisms for the implementation of charging infrastructure should provide incentives for the implementation of smart charging stations with integrated energy management.
- Develop inductive charging technology and unlock synergies with automated driving. Government research funding should be provided to intensify research and standardisation work in this field. A special focus should be put on autonomous parking and charging of EVs.

3.4.3. Market-Ready Products and Services

- Roll out of smart meter gateways to enable secure communication between charging infrastructure and system operator. The smart meter rollout has been delayed in Germany by high security requirements and a protracted certification process. The rollout is expected to start at the end

of 2019. Smart meter gateways are an essential element in the communication chain between charging infrastructure and the electric grid.

- Implement a mechanism to communicate the status of the energy system, e.g., by dynamic pricing of electricity as a function of grid status. Besides technical innovations, efficient business processes are needed to minimise the transaction costs and make demand side management of charging infrastructures profitable.
- Create transparency for charging prices and billing schemes. This can be achieved by decoupling the operation of charging infrastructure and charging services, through regulations on pricing for EV charging or through a web-based price comparison platform. This would limit the power of charging oligopolies and strengthen consumers.

3.4.4. Social and Economic Impacts

- Reduce local air pollution through sped up market diffusion of EVs to minimise health risks caused by particulate matter and nitrogen dioxide and to comply with EU regulation.
- Seamlessly integrate public charging infrastructure into public spaces. Since public space is limited in urban areas, a seamless integration of charging infrastructure needs to be achieved in order to gain public acceptance for EVs.
- Change charging habits to comply with fluctuating energy supply through automated energy management. This has to be achieved without limiting the mobility of EV drivers. Automation and streamlined service products help to gain acceptance through minimised additional effort for the EV driver. The visualisation of cost and ecologic benefits would be beneficial for user acceptance.

4. Discussion

The created vision represents an optimistic but realistic baseline scenario for Germany. As shown in chapter 1, countries like Norway or the Netherlands are following an even more progressive path. The roadmap and the derived recommendations for action in Sections 3.3 and 3.4 show a clear need for technologies and regulations that enable cross-sectoral data flows in order to build efficient energy management systems. Especially smart meters, standardised communication interfaces and operation processes are required.

In contrast to other European countries, the German smart meter rollout is only just about to start. The reasons for this are high security standards and a sophisticated certification process, defined in the "Act on the Digitization of the Energy Transition" [40]. Together with the smart meter rollout, the implementation of standardised communication interfaces builds the foundation for a smart charging infrastructure. Thus, EVs could provide energy system services like load management or active reactive power management. If more charging points per EV are installed, longer connection-times will become more common, especially at work and overnight. In that case, the utilizable battery capacity for energy system services would increase significantly.

In the near future variable energy prices could be used to communicate the availability status of grid capacity, setting incentives for grid-suitable behaviour. The large battery capacity of the EV fleet would be used beneficially for multiple purposes. Multifactorial control schemes need to be developed to prevent EVs from reacting to market signals all at once, creating network congestion problems. This topic has been researched intensively, e.g., [55,56], but static regulation is hindering the development of products and services so far. Taxes and levies for the different energy sources need to be adapted to unleash the potential of flexibility, not only of electric vehicles. High taxes and levies on renewable electricity make it difficult to use dynamic electricity pricing as a steering instrument. When adapting existing or developing new regulations the resulting user experience should be focused on. Otherwise, user acceptance could become a problem.

Three studies will be highlighted, which complement the innovation paths and recommendations presented here for action for the integration of EVs into the energy system. A v2g technology roadmap for residential charging, focused on the situation in the United States [57], supports the claim for

smart charging infrastructures with standardised communication interfaces and integrated energy management. The study describes these technological aspects in detail while lacking an integrated view on the overall innovation system.

A German meta-study [54] regarding the research on grid integration of electric mobility evaluating 157 scenarios from 60 different studies also confirms that electric mobility can provide flexibility for the grid through exploiting local synergies with renewable energy generation. The focus of this study is shifted more to aspects of the electric grid, but the key innovation is also seen to be energy flow management for grid-suitable charging. While the study identifies grid-related research demands, it lacks demands for an innovative regulatory framework and user-friendly products and services. Furthermore, interdependencies between different research demands are not discussed. The study, however, gives a comprehensive overview on current research activities.

In addition to this, a German think tank published '12 Insights into the Verkehrswende' [58] with a focus on the transformation of the transport sector for the energy transition. This study explains the status quo and necessary developments. It is addressed to the informed public and does not give deeper insights into technologies and dependencies in innovation paths.

Our study complements the state-of-the-art through its specific focus on technical innovations and innovation policies. This policy driven approach highlights different topics, especially when it comes to framework conditions and funding of key enabling technologies. The other studies mentioned above, provide additional information on specific technological topics like v2g or grid management.

5. Conclusions

The presented vision shows that electric vehicles could dominate the car market by 2035. Lately, policy and industry in Germany have sent strong signals supporting this vision. Despite this, the vision described in this paper still has potential to become more progressive if the goals of the Paris climate agreement are reached. Based on a gap analysis comparing the status quo to this vision, a technology roadmap for further progress in the integration of EVs into the energy system has been developed. Thus, two innovation paths have been identified. One focussing on the deployment of a smart charging infrastructure and the other focussing on exploiting the synergies autonomous EVs can provide. These innovation paths have been translated into twelve recommendations for action covering socio-economic and regulatory framework conditions, enabling technologies, market-ready products and services as well as social and economic impacts. The most important measures to trigger innovation were identified to be a reform of taxes and levies on electricity, the implementation of communication standards into EV and charging products, a sped-up smart meter rollout, a standardisation of billing and grid integration processes for charging infrastructure, the development of energy system services provided by EVs, the development of methods to communicate energy system status and the integration of EVs into multimodal transport schemes.

Author Contributions: Conceptualization, S.W. and R.K.; Data curation, R.K.; Formal analysis, R.K.; Methodology, S.W. and R.K.; Project administration, S.W.; Supervision, S.W.; Visualization, S.W.; Writing – original draft, S.W. and R.K.; Writing – review & editing, S.W. and R.K.

Funding: This research received no external funding.

Acknowledgments: The authors would like to thank the German Federal Ministry for Economic Affairs and Energy (BMWi). The presented results are part of the accompanying research for the funding programme "ELEKTRO POWER II: Elektromobilität—Positionierung der Wertschöpfungskette", which was funded by the BMWi.

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

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