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Innovation needs for the integration of electric vehicles into the energy system

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Summary

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. Thus, this paper aims to identify the need for future research, development, standardisation and regulation to provide recommendations for action.

Keywords: EV (electric vehicle), strategy, energy, smart charging, regulation

1 Methodology

The chosen approach, visualized in figure 1, is based on evaluations of literature and research databases as well as the validation of the findings with 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” [1]. The first step was the generation of a vision for the integrated energy and mobility system. This vision was then compared with the state of the art in electric mobility and energy technology. A gap analysis was carried out to identify upcoming challenges that need to be addressed to achieve this vision. Then the relevance and completeness of these challenges were validated in an expert workshop. This workshop was held in April 2018, with participants from science and the relevant industries. Amongst them there were also participants from the ELEKTRO POWER II programme. On this basis, together with these experts, a visual roadmap has been developed. This 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 dependencies and synergies. The resulting roadmap was compared to ongoing and planned research activities. These research activities were mapped by analysing scientific literature and by mining international research databases such as Förderkatalog (Germany) [2], CORDIS (EU) [3] or the NSF research spending & results database (USA) [4]. A gap analysis of success factors and ongoing research activities lead to the identification of innovation needs. In the final step, recommendations for action were derived from the identified innovation needs. This study has been carried out with a special focus on the German transport sector. Due to the similarity of transport sectors throughout Europe, the results are partly transferable to other EU countries.

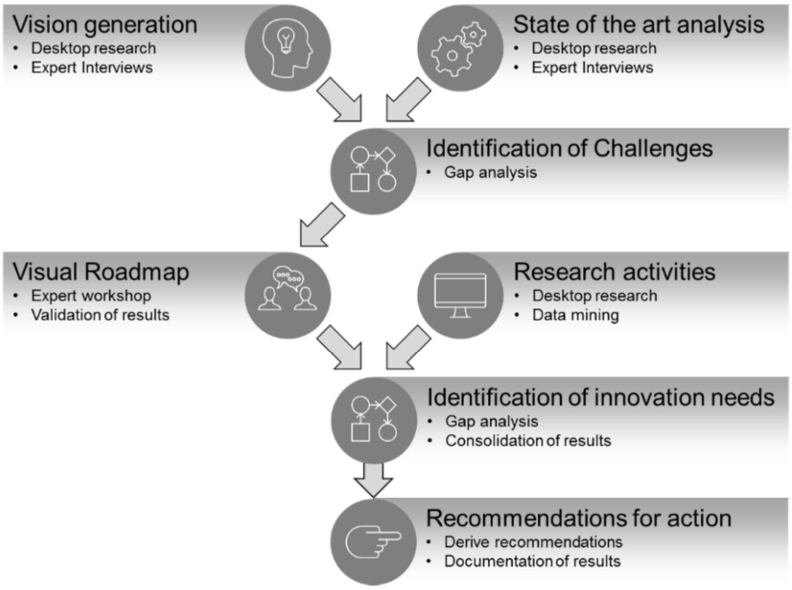

Figure 1: Applied methodology for the identification of innovation needs

2 Vision

In future, road mobility will be provided by electric vehicles (EV) while exceeding the level of comfort of internal combustion engine (ICE) vehicles. Through intelligent energy management EVs will contribute to the transition of the energy system towards a fully renewable energy supply.

2.1 Current status and further development of the transport sector

The transport sector counts for 19.5% of the European Union greenhouse gas (GHG) emissions [5]. For Germany it is 18% based on 2018 data [6]. Constant improvements in vehicle technology and specific efficiency have been achieved ever since. Unfortunately, the overall effect compared to 1990 is null and void. The associated emissions even increased to 170.6 Mt CO_2eq in Germany [7]. The EU GHG emissions in 2017 are 28% higher than in 1990 [8]. This is mainly caused by a growing economic activity and transport demands, but also due to the tendency towards heavier and stronger vehicles.

In the following years, new 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 the CO_2-emissions up to 2050. The German transport sector shall reduce its CO_2 equivalent emissions by 45% to 95 Mt in 2030 [8]. In February 2019 a proposal for the national climate protection law was published, to make those objectives binding [9]. 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 [10]. 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. The EU target for sales of EVs and plug-in hybrids is 35% by 2030 [11]. Figure 2 gives an overview of some of the most relevant objectives regarding the market share of electric vehicles.

Several studies demonstrate, that with the momentary share of renewable energies in electricity, EVs are already showing a better climate balance than comparable fossil fuel cars [13][14][15]. Different vehicle sizes and usage scenarios were taken into consideration. The BMU evaluation shows an advantage between 16% and 27% of the CO_2 emissions per kilometre over the entire vehicle lifecycle for 2017 in Germany, growing to 32% and 40% in 2025, based on the improving energy mix [13].

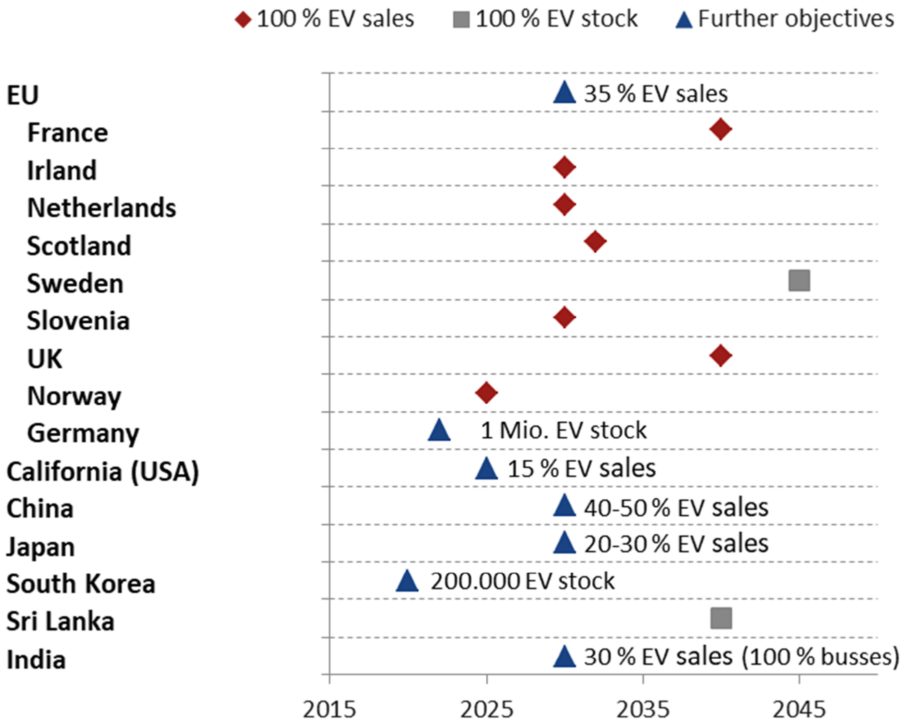

Figure 2: Political objectives in e-mobility, based on [12]

Global electric vehicle sales are growing rapidly showing a two digit growth in all major markets. China has become the largest market with 579.000 EVs sold, while Norway is the most mature market with a 39% share of EVs in the car market in 2017. Overall, the global stock of EVs passed 3 million in 2017 [12]. With EVs being the preferred choice to decarbonize the transport sector, this market will continue to grow (see figure 3). If the Paris climate goal [16] to keep global warming well below 2 K shall be met, the market share of electric vehicles needs to follow the *extremely progressive* scenario in figure 3, surpassing the established regulation objectives.

A more moderate approach (*progressive scenario*) 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. Thus countries like Norway, Ireland, Slovenia, and the Netherlands have set political goals to reach a 100% EV market share by 2030 [12]. France and the UK are following by 2040 [12]. These goals are reflected by a rising number of electric vehicles available on the market. The two conservative scenarios represent the business as usual approach (*conservative*) and a renaissance of the internal combustion engine (*extremely conservative*) through cheap fuel prices and further optimization of combustion engines. The study “climate paths for Germany” shows that 33 Million electric vehicles in Germany in 2050 would require around 63 TWh of electricity, but a substitute 175 TWh of fuel [25].

Also, further alternative drives and fuels need to be considered and will play an important role to acclaim the objectives of the transport sector. Electricity (in perspective 100% renewable) can be converted into hydrogen or synthetic fuels for example. Those can have advantages in range, recharging and using existing infrastructures and even combustion technology. On the other hand, the acquisition costs are higher [26] and energy efficiency is lower in comparison to battery-electric vehicles (BEV) have to be seen. A fuel cell electric vehicle (FCEV) requires more than twice as much primary energy as a BEV for the same distance. For synthetic fuels, approximately five times more energy needs to be generated [27]. 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 applications where battery driven technologies are not as suitable. This is especially the case when high energy densities or long range operation is needed, for example in aviation or long range transport of goods.

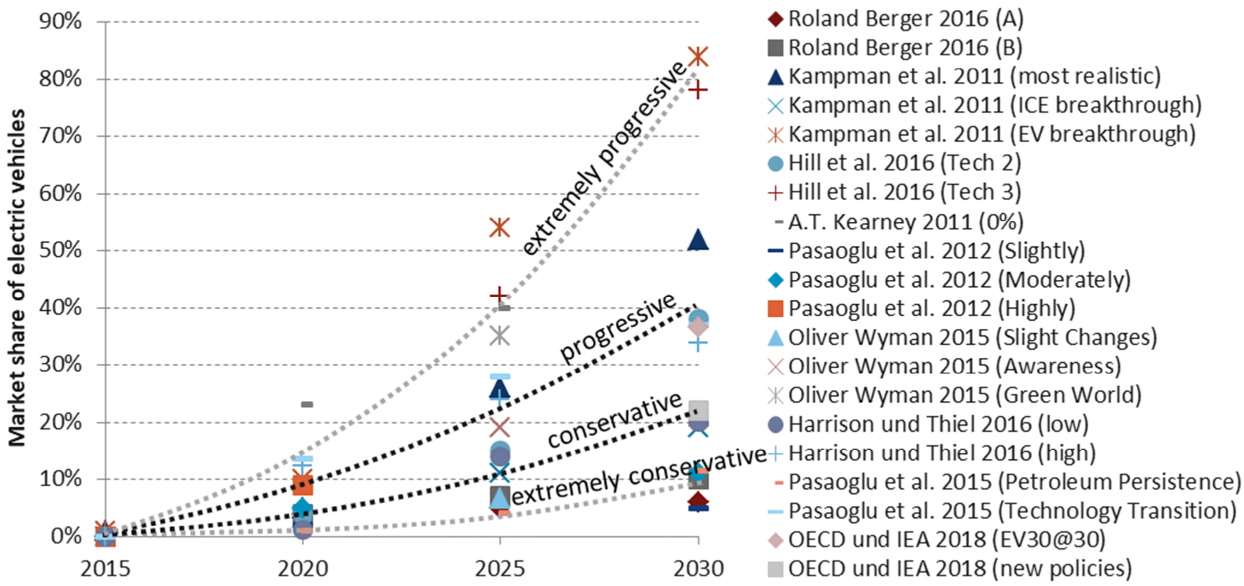

Figure 3: Projection of the EV market development until 2030 based on [12], [17], [18], [19], [20], [21], [22], [23], [24]

2.2 Current status and further development of the energy sector

The energy system faces the transition from fossil to renewable sources. In 2017, renewable energies already accounted for more than two thirds of the globally new installed electricity generation capacity [28]. Wind and solar energy are becoming the new major electricity generation technologies [28]. While reducing GHG emissions, these technologies are decentralized and show very volatile energy generation patterns. At the same time, new energy consumers like EVs, heating appliances or electrified industrial processes also increase the volatility of the energy demand. Since most of the energy consumers and renewable generation capacity are connected to the distribution grid, a huge demand for smart energy management and storage solutions is created [29]. The pioneers of this development are countries such as Denmark, Germany, Ireland, Spain, Portugal and some states of the USA, whose share of volatile renewables in power generation already exceeds 20% [30]. As other countries are following their lead, technologies for the management of volatile energy flows are moving into the focus of energy research.

3 Challenges for the integration of EVs

A variety of challenges for the integration of EVs into the energy system can be found, including technical issues, international regulations and standards as well as user behaviour and functioning business cases. The different aspects were discussed during the workshop, in order to be considered in the development of the following roadmap.

As of today, in Germany and the majority of countries, only in exceptional cases the share of EVs on the road causes a major impact on the energy system [31]. But the situation is changing, with more and higher powered charging points being installed and a broader product range on the vehicle market becoming available. Starting in weaker distribution grids, the potential influence on the electricity grid will increase. Not only the overall electricity demand is going to rise, also an uncontrolled simultaneous charging might lead to critical conditions with power peaks and fluctuations in the grid. Those would cause the application of costly emergency measures. Additionally, seasonal effects have to be considered for the energy system. Not only the electricity demand for heating of EVs raises with lower ambient temperatures [32], also heat pumps and other applications in the heating sector have higher demands.

In order to assure grid stability, grid extensions or suitable charging management will be required. Power generation capacity from renewable energies and power demand in the transport sector will need to be more closely aligned [33]. Studies are showing that with a working charging management a market penetration of EV of up to 30% should be achievable without additional investments into the electricity grid [34]. 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 [35].

In public areas 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. That does not leave a lot of room for grid stabilizing 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 defines a communication interface for that 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 standardization for charging and technological specifications still have to implemented as well as a legal framework for flexible electricity prices to create incentives for grid beneficial charging [36][37].

4 Success factors

The major challenges of 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 roadmapping workshop [38] to validate findings and to derive success factors for the integration of the mobility and energy system. The resulting roadmap is shown in figure 4. 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 visualized by solid arrows while synergies are represented by doted arrows.

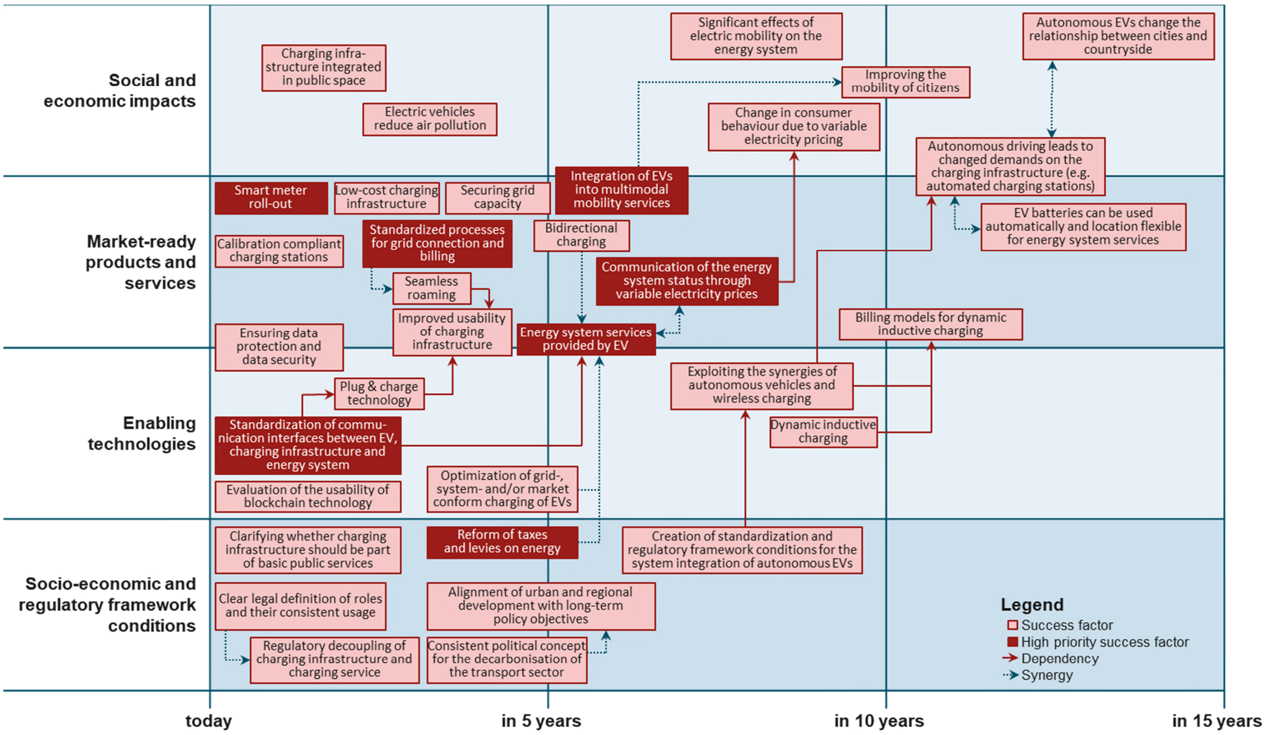

Figure 4: Technology roadmap for the integration of electric mobility into the energy system
(Source: iit/Begleitforschung ELEKTRO POWER II)

The roadmap shows a clear need for technologies and regulations that enable information and managed energy flows between electric vehicles and the energy system. Especially smart meters, standardized communication interfaces and operation processes are required. In contrast to other European countries, the

German smart meter roll-out 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 Digitisation of the Energy Transition” [39]. Together with the smart meter roll-out the implementation of standardized 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 are installed, especially at work, and overnight connection of the EVs can become more common, then the potentially available battery capacity for energy system services increases. An evaluation of 157 scenarios from 60 different studies published in December 2018 also confirms: electric mobility can provide flexibility through local synergies with the renewable energy generation. The key element is the energy flow management for grid-suitable charging [40].

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. by [41], [42] or [43], 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 will become a problem.

5 Ongoing research

The German Government is implementing the goals of the National Development Plan for Electric Mobility [44] through a package of measures. The National Platform Future of Mobility (NPM) accompanies the transformation of the mobility sector with the development of reliable timelines for these measures, expert discussions and recommendations on strategic decisions [45].

The Federal Ministry for Economic Affairs and Energy (BMWi) is currently supporting 13 projects through its funding programme “ELEKTRO POWER II: Elektromobilität – Positionierung der Wertschöpfungskette“. The focus lies on the integration of e-mobility into the energy system transformation process, the optimisation of the e-mobility value chain, the further development of inductive charging systems in publicly accessible areas and cross-cutting topics, such as legal, security and standardisation questions [37][46]. The chart “Innovations for electric mobility” shows the individual projects in the overall energy system in Germany. Furthermore the BMWi will synchronise the recently started charging infrastructure projects in the “Sofortprogramm Saubere Luft” [47] with activities regarding the roadmap "Standardisation strategy for cross-sector digitisation in accordance with the Act on the Digitisation of the Energy Transition" [48] and the "Barometer Digitisation of the Energy Transition" [49]. The objective is to achieve a further elaboration and consolidation of grid suitable charging aspects, the legal framework, standardisation questions and security.

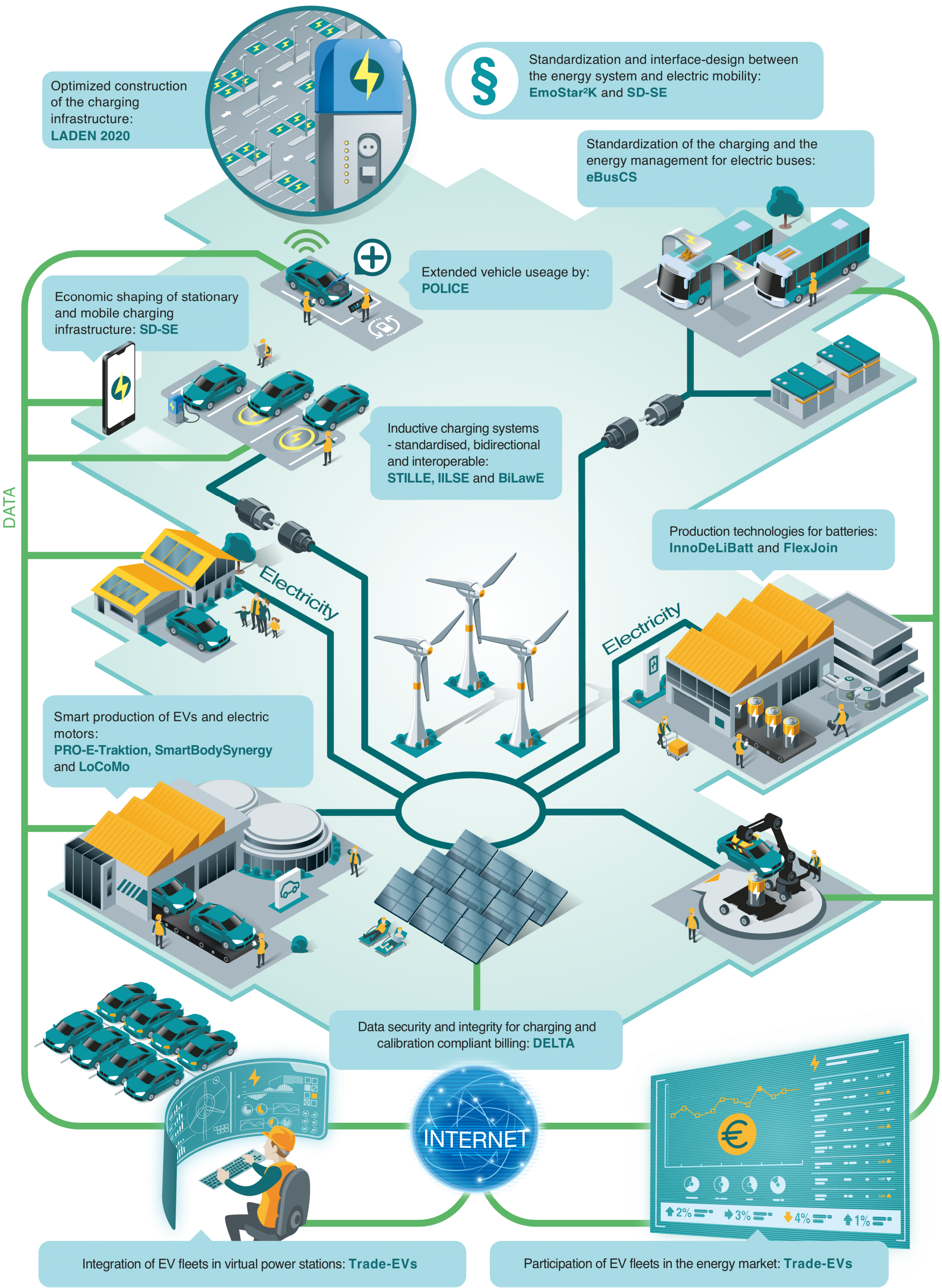

Figure 5: Innovations for electric mobility – ELEKTRO POWER II
(© LHLK/Begleitforschung ELEKTRO POWER II) [43]

6 Conclusion

The integration of large quantities of EVs into the energy system will be a difficult but solvable task. Theoretic concepts have been evaluated intensively. These studies show that with a suitable energy management system, a share of 30% EVs on the roads would not cause major problems. Beyond that, the next steps would be to develop ready-to-market technologies for gathering real time information on electricity generation and the status of the distribution grid. The energy management algorithms for EVs need to be implemented into smart systems to automate optimised charging. Furthermore, roles and responsibilities in the integrated energy and mobility system need to be defined to develop consistent standards and regulations. This is also relevant for the standardization and implementation of communication interfaces, which still are a bottleneck for the development of energy system services provided by electric vehicles. With flexible charging and contracting energy from renewable sources, EVs can become a supportive rather than an interfering element of the energy transition.

Acknowledgments

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