Research Campus Mobility2Grid: From Lab to Reality

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***Abstract*—Increasing numbers of electric vehicles and renewable power generation can be beneficial for curbing carbon emissions. Vehicle2Grid technologies are available for integrating such vehicles into power networks that are fed with volatile renewable energies. Hence, cars, busses, and trucks can serve as both flexible energy storage and source. This paper summarizes results of the Mobility2Grid research project in the fields of grids and vehicles, acceptance and participation, and business models. As the paper focusses on the question of how to get from research results to application, it also features questions of successful cooperation and communication within the project. It is shown that it is technologically possible to apply Vehicle2Grid technologies in real-life scenarios; that user acceptance can be facilitated; and that potentially viable business models exist.**

Keywords - vehicle2grid; smart grid; business models; participation

I. Introduction

The German Energiewende, or energy transition, has become an internationally known concept for reducing the share of fossil and nuclear fuels in the energy sector, gradually replacing them with renewable energies. In order to achieve the implied goal of reducing carbon emissions, this occurs not only in electric power generation, but also in the heating, cooling and transport sectors. Sector coupling helps making the transition to a higher share of renewables possible. A central challenge in this regard is storing energy. In contrast to the preexisting, centralized power system, a power system with a high share of renewables needs storages that can buffer volatile energy. In this context, decentral storages close to the customer are of particular interest.

Using the batteries of electric vehicles as flexible storage options is one possible solution that is proposed and tested in various studies and projects [1-3]. In the same vein, the central idea of the research project Research Campus Mobility2Grid (M2G) is to integrate electric vehicles into decentralized smart energy grids through intelligent, bi-directional charging and energy storage technologies using batteries as well as Power2X technologies. The focus is on urban areas with a high density of vehicles, following specifically the assumption that cars are parked for over 90 % of a day [4], thus potentially being available as a storage option during this time. Furthermore, with the ongoing electrification of urban vehicle fleets (car sharing, public buses, service vehicles and logistics), a smart grid can be conceived which can benefit from scheduled electric vehicle operations and dwell times. A distinctive feature of the M2G project is to build upon existing technologies, improving them and making them feasible for application in a highly interdisciplinary cooperation between academia and science.

This paper gives an overview of the results achieved during the first half of Mobility2Grid with a focus on transferring research into application. The next section gives a short overview about the project layout and goals. Parts 3 to 5 summarize outcomes in four areas that are exemplary for the transfer into reality: infrastructure and technology, acceptance, and business models. Section 6 summarizes some central experiences regarding the cooperation of competing stakeholders and communication. Both aspects are helpful for understanding implementation potentials of research results. Sections 3 to 6 build upon papers, studies, and internal reports that were created within the M2G project. The final part gives a conclusion and a short outlook.

II. Mobility2Grid: A Public-Private Partnership for Energy and Mobility

By definition in the project funding outline, the physical location of the Research Campus plays a vital role. M2G thus creates a “living lab” on the EUREF (European Energy Forum [5]) Campus in Berlin, Germany, the location of around 80 companies and research institutions committed to sustainable solutions in energy and mobility. 23 of the project’s 36 partners are located at EUREF, benefitting from short ways and informal communication possibilities. The partners are organized in seven working groups that are described in the following paragraphs. The overarching project aim is to make mobility, heat, and power supply safe, affordable, and based on renewable energies, using Vehicle2Grid technologies. A first funded phase from 2013-2015 served for setting up the structure, gathering partners and topics, and feasibility studies. From 2016 to 2020, M2G is in its first “main phase”, hence having completed the first half of this stage in 2018. Application for funding for another five years is possible.

An essential element of M2G is the work group “Smart Grid Infrastructures” which models and optimizes an integrated energy supply system in order to combine power, heat, and mobility. The work group “Connected e-Mobility” develops solutions for the operation of energetically connected electric car fleets in inner-city areas. “Bus and commercial transport” works on introducing electrified vehicles in urban public and commercial transport. Recently, a charging station for electric buses has been put into service. It includes one uni- and one bidirectional charging point. Depots of large electrified fleets and energy-efficient logistic concepts are also considered. Results of these working groups are presented in sections 3 and 4 as examples for technical project tasks.

Linking and processing data, the work group “Digital Spaces” creates interfaces between mobility and energy systems. Their aim is to tap innovation fields with the help of a digital platform that gathers and provides data for the development of new services. “Education and Knowledge Transfer” provides new academic and professional education formats, educating employees of companies that plan to introduce Vehicle2Grid solutions. The work group “Acceptance and Participation” deals with the societal side of the transformation process that is entailed by both energy and mobility transition because only broad acceptance guarantees the diffusion of innovations. Operating and demonstrating the micro smart grid in the EUREF area is task of the work group “Operation and Commercialization”. They also process research results from the other working groups into implementation projects. Results of the latter two working groups are presented in sections 5 and 6 as examples for non-technical challenges in the project.

III. Grids and Vehicles

A. *Electrified bus and grid integration*

In many cities around the world bus fleets are being electrified, and the batteries of these electric fleets (and other commercial vehicle) are a reasonable application scenario for a smart grid integration. Analysis of well-available data regarding factors such as distance traveled, road topology, and driving behavior facilitates an active energy management with an efficient energy supply. Smart charging strategies and several optimization techniques can be adapted which helps lowering energy costs and avoiding grid congestion. As shown in [6], it is proposed to integrate electric bus fleets in Virtual Power Plant (VPP) operations, thereby obtaining optimal charging (and discharging) schedules. They also identify possible operation procedures for charging processes applicable at intra-urban depots. Moreover, the busses can be used as additional mobile energy sources for energy market participation and the provision of power system services. They also show that optimized charging strategies allow reducing the peak loads at an intra-urban depot while utilizing renewable energy sources for charging processes and that electric bus fleets can provide control reserve capacity services.

Taking into account the increasing energy demand for charging processes and the resulting, increased complexity for power systems, it is especially important to design the integration of charging infrastructures as advantageous as possible. Lauth et al. [7] present the set-up of a charging infrastructure that is integrated into the local smart grid at the EUREF Campus. Fig. 1 gives a schematic overview about the campus smart grid and the integration of the bus charging infrastructure, which consists of a sub-distribution and a charging station. The latter is divided into a compact charging unit with an integrated AC/DC conversion and a front-end to connect with the electric bus. Two types of charging stations are established for the electric bus:

- a unidirectional system, which is only for charging (e.g. at terminal stations), with an automated pantograph as front-end, and
- a bidirectional system, which additionally has a feed-in possibility (e.g. for depots), with a manual Combined Charging System (CCS) connector.

Communication between the vehicle and the front-end of the unidirectional system is realized via Wi-Fi. The charging process starts automatically as soon as the vehicle stops in the defined position and after short safety checks are completed.

Amongst others, a measurement converter as part of a bidirectional smart meter is installed in the sub-distribution to allow the use of load-dependent and time-variable charging and discharging processes. It also features a number of system protection and measuring devices according to E VDE-AR-N 4105. The communication infrastructure is implemented as

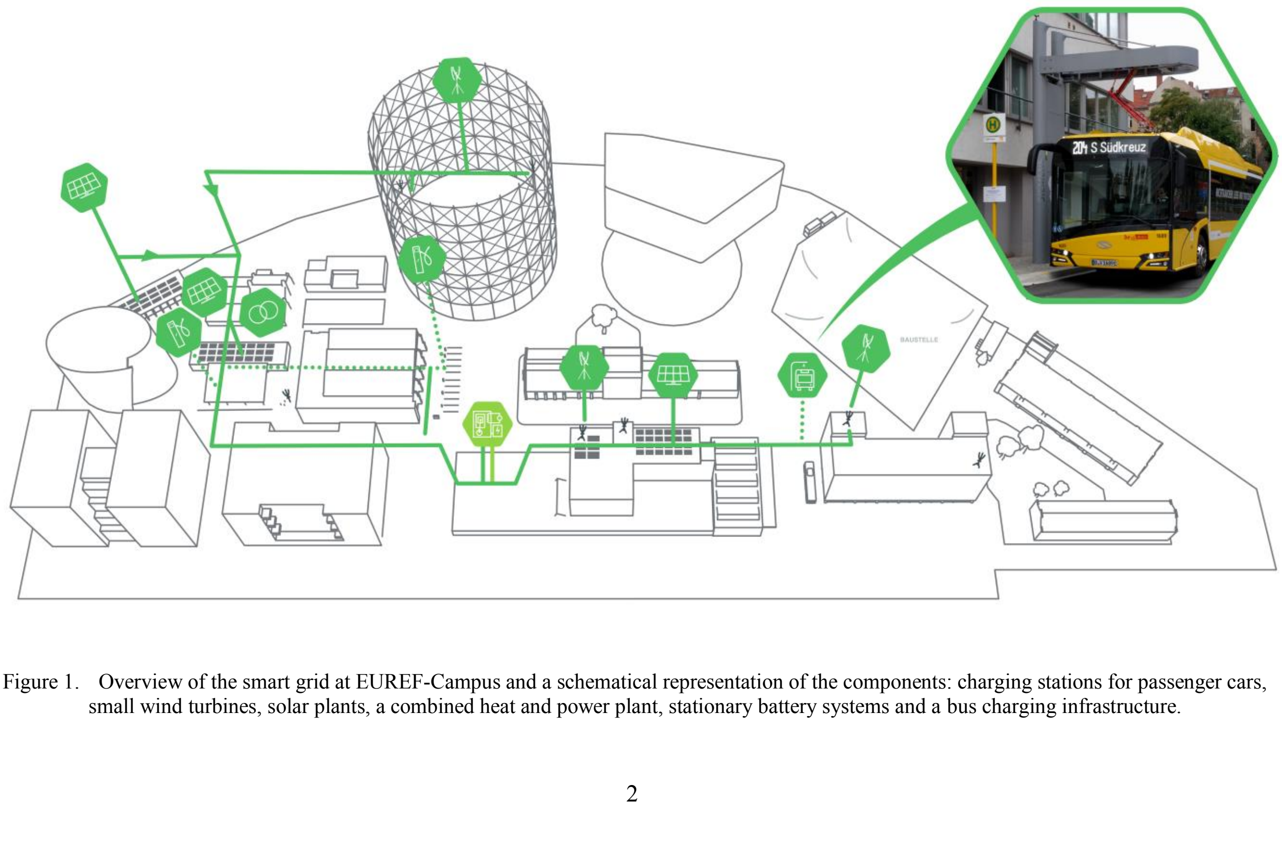

Figure 1. Overview of the smart grid at EUREF-Campus and a schematical representation of the components: charging stations for passenger cars, small wind turbines, solar plants, a combined heat and power plant, stationary battery systems and a bus charging infrastructure.

point-to-point and point-to-multipoint connection via ModBUS TCP/IP for real-time distributed control. The operation of the smart grid is automated and realized with supervisory control and data acquisition (SCADA) and energy management systems (EMS).

The bidirectional data exchange enables control and regulation possibilities. Different entities are involved in the charging process and have different remote access options to the electric bus and the charging infrastructure:

- Electric Vehicle Supplier / Aggregator (EVS/A): real-time data supplier of a number of electric vehicles for an improved calculation of the charging and discharging schedules
- Charging Point Operator: service purposes and setting configurations, influencing the charging and discharging power or current in certain limits during a charging process
- System Operator (SO): occasional adjustment of the feed-in process, turning the charging point off/on, gradually reducing the feed-in power of the bidirectional compact charging unit
- Virtual Power Plant (VPP): placing bids and participating in energy markets under the same market entity, thus the possibility to include electric busses as additional energy sources

So far, the unidirectional system is in operation and used to validate two main charging strategies:

- opportunity charging intends to charge the batteries several times during operation hours, usually during dwell times at terminal stations, therefore with higher charging power than compared to:
- depot charging, which intends to charge the batteries during longer operating pause in the depot, usually overnight with a manual plug.

Both charging strategies are tested at the EUREF Campus with a bus that is deployed on a fully electrified bus route as support during peak traffic hours. Comparing the planned and the actual charging process gives some significant differences regarding a time delay caused by a delayed arrival of the bus. This is relevant for both the VPP operator and the SO but also for the local smart grid and power system services. This demonstrates prototypically what contribution electric buses and other electric vehicle fleets can make to a future energy supply.

B. Using sharing car fleets as flexible storage options

Batteries of private electric cars can also contribute to connect the mobility and the energy sector. This becomes especially true when electric cars start to become a mass market. However, their availability, user acceptance, and a crucial fleet size can be challenging factors for research about impact on the electric grid. Car sharing can be part of the solution since it is becoming more established [8] and is one component of a greater mobility transition. For this reason, Noeren et al. [9] analyze the impact of shared cars on power distribution networks and their potential to contribute to local grids through Demand Side Management (DSM). This has the advantage of data availability and good prediction of usage times.

The analysis was conducted based on data published by the car sharing provider DB Connect. After filtering (transporters, bikes, very short and very long trips), the team used data of around 1,200 vehicles that made a total of 342,350 trips in Germany within two and a half years. These data sets of fossil-fueled car rides were then examined regarding the potential to substitute the vehicles with electric cars. Decisive factor in this regard is the range: 75 % of all trips were below 110 kilometers, which is within the range of a 20 kWh electric vehicle. Only 10 % of the trips were over 260 km. Under the assumption that charging opportunities exist during a long trip, it was concluded that almost 100 % of all trips could be done with electric vehicles.

In the next steps, four car classes (mini, small, compact, medium) were parametrized according to average capacity, consumption, and charging capacity figures; and four distinct charging strategies were defined. In accordance with the German National Platform for Electric Mobility, these included

- a reference scenario of full power charging as soon as the vehicle is plugged in until the battery is fully charged,
- a load reduction scenario with reduced charging capacity throughout the cars’ standing time until the battery is fully charged,
- a load shifting scenario that aims at charging the battery until the next trip, using any allowed charging capacity, and
- a scenario in which, additionally to load shifting, flexibility is gained through feeding power back into the grid (Vehicle2Grid or bidirectional charging)

Other important factors for the charging scenarios are the time span needed to fully charge a car in the reference scenario, and the parking time in which cars can be used for charging and discharging. If a car is parked longer than needed for the reference charging scenario, potential for load shifting arises. For this, the status of charge upon arrival and the chosen and possible charging capacity matter. Subsequently, load profiles and energy demand for each of the roughly 1,200 cars were laid out on a per-minute basis and aggregated. This allowed for depicting potentials for DSM for the respective charging strategies.

The analysis shows that the average charging load is up to 5.5 kWh, which is around 60 % of the maximum charging capacity of 8.5 kWh. For the examined charging strategies, load shifting and bidirectional charging are possible at almost any given time, even if the potentials vary depending on the chosen strategy. This implies that loads can be increased by the same factor. Fig. 2 shows the varying potentials for the four charging strategies on weekdays, Saturdays and Sundays. Results both on an aggregated level and limited to a certain area hint towards that there is a benefit of using electrified car sharing fleets smart grids.

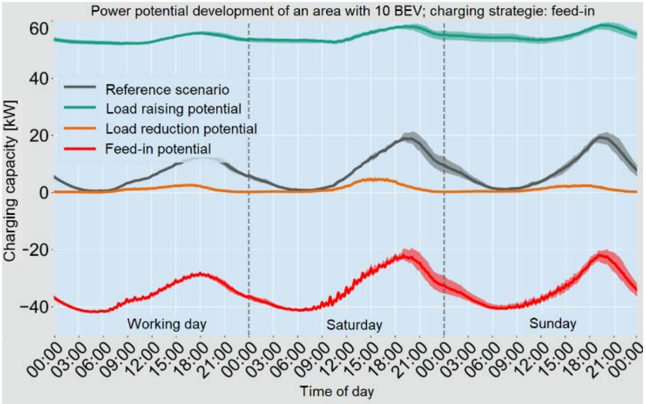

Figure 2. Power potential development for energy, load and DSM profiles with different charging strategies. [8]

IV. Including the Human Factor: Acceptance and Participation

While the previous section showed technical solutions and feasibility for a Vehicle2Grid concept, other decisive factors remain that could inhibit larger scale application: will users accept the new technologies? And are there viable business models so that companies deploy them?

The developed technologies are of little use for increasing the share of renewables in the power grid or the number of electric vehicles when people are not willing to use these technologies. This is valid for both private and professional users. Technology acceptance is influenced by attitudes towards the technology in question, as well as its perceived usefullness and easy usage. Research hints towards that moral attitudes and being able to get in touch and test new technology also play a role in accepting technologies [10-11]. M2G takes this into account and lets users participate in the development process and asks them about their perception of the developed technology.

Due to the low availability of electrified commercial vehicles, it was not yet possible to conduct extensive surveys on the accepctance of electrified vehicles that are integrated into smart grids. A small interview series with six drivers of a newly introduced hybrid street sweeper still points towards some relevant findings.

The drivers were diverse regarding their age, their affiliation with the company, and the frequency of their shifts with the hybrid sweeper. It was positively evaluated regarding its user-friendliness, performance, technical reliability, and integration into operational processes. The main challenge lies therefore in planning: if the vehicle is suitable for the distance and the degree of pollution, deployment is feasible. The users also pointed out that in case of higher degrees of pollution, the battery requires active energy management. While charging is not seen as a problematic issue, insecurities concerning maintenance exist. The users experienced high-frequency noises of the machine as very negative and were both curious and skeptical toward long-term usage of the machine. Skepticism existed also regarding cost and battery lifespan. Yet, on a general level, they perceived the machine as a contribution to the energy transition and as fitting to the company's modern image.

Altogether, there was a balance of curiosity and skepticism regarding the hybrid sweeper. The generally positive evaluation confirms that it is feasible for companies to deploy vehicles with a new technology, especially if their performance is perceived similarly or better in comparison to existing machines.

While employees might only have a limited impact on their employer's choice to use electric vehicles, private users' decisions are voluntary and depend on a variety of factors. In order to include citizens into the process of integrating electric vehicles into power grids, a variety of methods are applied. The steps taken for ensuring citizen participation are shown in Fig. 3.

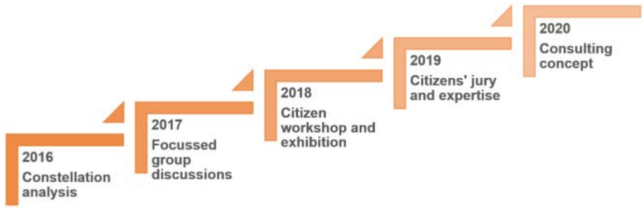

Figure 3. Participation steps.

To begin with, project members from all working groups participated in analyzing the current constellations in the energy and mobility transition in general and at the campus area [12]. In a second step, the discussion focused upon desired constellations that would facilitate Vehicle2Grid application at EUREF [13]. A scheme of the latter constellation is depicted in Fig. 4. Its upper left part shows a M2G "total package" which includes the Research Campus' specific characteristics and M2G offers. It connects technical elements of the smart grid with service and education offers that result from the project. It is also bidirectionally related to the upper right part of the figure that includes a potential M2G brand. This includes all M2G partners and the project association, together making the energy and mobility transitions as well as their connection tangible both at EUREF and beyond. One example for this is the so-called zeeMobase (Zero emission energy and Mobility Base) that was set up in cooperation of several partners which is both a showroom for and actual core of the micro smart grid. The lower part of the figure contains business ideas (as hybrid elements) that are derived from four areas of technical smart grid elements. The red elements depict potential outcomes and benefits.

The workshops showed inter alia that in the first project year, vehicles and infrastructures were mostly lacking and that legal regulations impede positive developments. Another result was that the project members' business cases are not yet sufficiently connected with merging the energy and mobility transition. At the same time, existing business cases are focused on singular technical elements such as charging opportunities, not on the intersection between energy and mobility (cf. section 5). Better conditions for business models would include a tight integration of the smart grid and electric mobility, resulting in a number of connected services. Some recommendations and strategies were derived, including agenda setting, communication, spin-offs, and strategic partnerships.

In a second step, the researchers conducted focus group discussions with members of an energy co-operative. Since this organizational form is highly participative, it might be key to citizen engagement in innovative technological fields. The discussion pointed towards the following factors as acceptance-increasing [13]:

- a “mobility guarantee”, allowing for flexibility and spontaneity,
- economic incentives, possibly by being able to use the cars, but at least through a compensation for battery usage,
- easy usage and operation and requiring as few behavioral changes as possible,
- functionality, safety and quality control,
- transparency regarding the system (also in order to understand who benefits),
- connection to carsharing and a wide charging infrastructure,
- a vision that includes more than mobility,
- ecological benefits.

The groups also discussed the benefits of co-operative structures (such as economic benefits for the members, transparency, flexibility, member and citizen engagement, and more) that could also increase acceptance when implementing M2G concepts. This shows that there are a number of factors and possibilities that can facilitate the acceptance of applied concepts.

V. Business Models at the Nexus of Energy and Mobility

The previous sections showed technological applications and ways to ensure and evaluate user participation and acceptance when putting new technologies into use. Another decisive factor for deploying research results is their economic viability, which also – and to start with – facilitates industry participation in research. Specific to the sector coupling of mobility and power is that there is, as of now, no single actor who provides integrated solutions. This is not at least due to the fact that “there exist neither a defined market

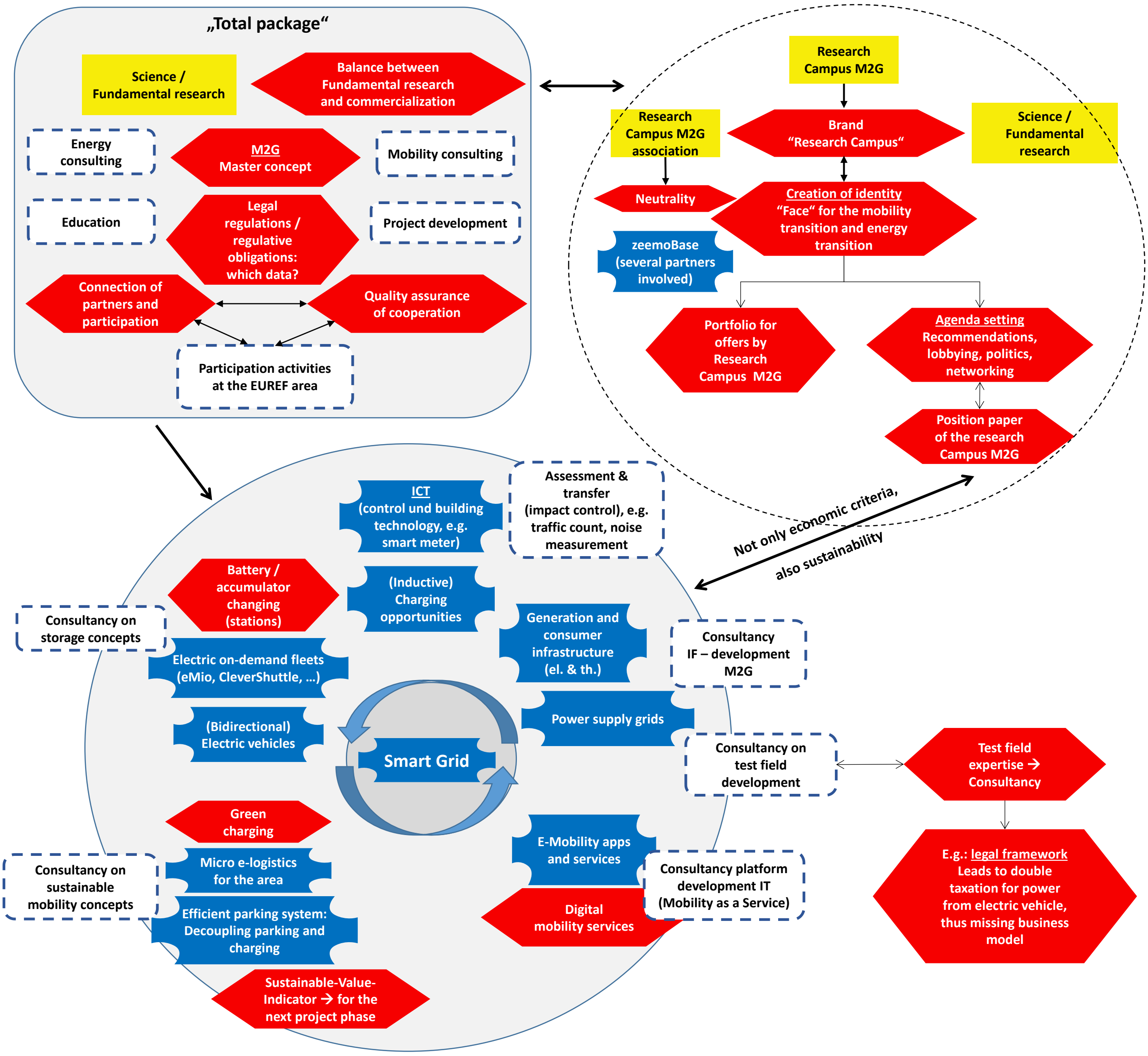

Figure 4. A scheme of a desired constellation for business models for the Research Campus M2G. Yellow elements: acteurs (single or groups); red elements: ideas, concepts, laws, communication (e.g. software licenses); blue elements: technical artefacts, hardware; white elements: hybrid types. Arrows indicate relations [11].

nor viable business models for most of the technical solutions and concepts […]. The technologies have not yet reached the market maturity stage." [14, p. 30]. That means one the one hand that there is no actor with strong experience with creating a business model in this realm; on the other hand, there is much space for creating innovative and new business models. Therefore, viable business ideas still need to be developed.

In order to assure that results find their way into practice, one working group deals specifically with the commercialization of research results and real-life operation of a smart grid. During the first two years, this working group regularly surveyed the other working groups regarding potentially deployable results ("potential screening") [15]. Some of these results include:

- a counselling concept for actors who want to transfer the M2G concept to other areas, with a specific focus on acceptance barriers,
- charging infrastructure operation by grid operators,
- using self-sufficient energy supply with renewable energies for decentral railway facilities,
- a data and service platform for mobility service providers that should stimulate the development of innovative electric mobility services, e.g. to facilitate access to charging infrastructure,
- training concepts (adapted to different target groups in industry, science, and administration).

These results are discussed and refined in practical workshops that support the development of the business ideas, which is an ongoing process. Using the business model canvas method, this already resulted in the creation of business ideas in some project fields, specifying required actions and resources. These include i.a. customer acquisition, feasibility studies, market research, process definitions, finding locations, IT support and infrastructure for apps and services, and staff trainings. In one workshop, the method was widened and included a business model navigator. Here, the participants discussed potential structures and patterns for their implementation idea and identified two that they deemed to suit best.

The next steps in developing these business ideas into business models depend on how mature the ideas are. If there is no specific and clear business model yet, another workshop supports further development. If this is not necessary, the groups agree upon the required next steps for implementation. Whilst some groups asked for repeated consultation at a later point, some ideas (e.g. training concepts) are already being implemented. In the latter cases, the project funding partly serves as the initial base for becoming self-sufficient. Creating such spin-offs is among the secondary funding goals. On the way there, the working group supports the business model development with practical issues such as billing models and speaker acquisition.

More focus will be put on calculations of profitability of the specific ideas, which have not been part of the chosen methods. It needs to be noted that legal conditions might change rapidly and thus also profitability perspectives. For the current German legal framework, Fig. 5 shows the power delivery chain from grid operator to consumer, clustered by operator groups. It indicates which laws are binding for which actors: grid operators and operators of customer installations (including charging stations and micro grids) act according to the German Energiewirtschaftsgesetz (Law on the Energy Industry), whereas end consumers and their vehicles are subject to the Erneuerbare-Energien-Gesetz (Renewable Energy Law). However, it is not clear who the end consumer is: according to the LEI, it is the charge point operator, and the REL does not define whether it is the charge point operator, the electric vehicle or its owner. This shows the complexity of differing legislations and their implications for business models, posing barriers for potential operators.

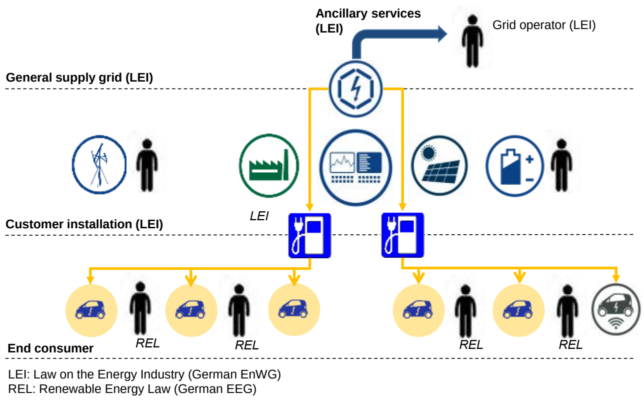

Figure 5. Operator model and legal frame for different actor groups. ©inno2grid

VI. Cooperation and Communication

Whether or not results of a research project are implemented and used depends on a variety of factors. The previous sections give an overview about technology that was developed and deployed within Mobility2Grid and about ways to facilitate and support the transfer outside of the project. While it can be assumed that no company will take part in a research project without a specific commercial interest, malfunctioning cooperation of diverse project members can impede even first steps of deployment. In M2G, organizations from science and industry cooperate that are very different with regard to size, topical focus, resources, and aims. Partially, there is also competition between some of the project members. Yet their expertise made it important to acquire these stakeholders for the project. Making sure that companies that both contribute and benefit from the project participate in it, some valuable experience was gained that adds to the project performance. It helps to understand these dynamics when aiming at the application of research results.

The situation of a newly arising business field leads to a situation in which "interaction between actors with different, field-specific types of knowledge appears to be a necessary condition" [14, p. 30]. Although getting competitors to engage in the same project was a complex process, engagement may be less surprising from this perspective. Organizations are dependent on knowledge they do not yet have, and the cooperation in a research project is a somewhat safe space for interacting with clearly set rules. Moreover, they have the possibility to influence the newly developing field to their advantage. Similarly, "engaging in these projects does not mean fundamentally changing the company's strategy but instead offers the opportunity to tap into new business areas" [14, p. 32]. These are obvious reasons for engagement and, given that industry partners see sufficient potential, eventually realization.

M2G made sure that responsibilities within the project are clearly differentiated and set up a cooperation agreement. All project members signed it. The agreement outlines requirements and rights within the project. It includes the right that all results that were achieved and published within the project may be used by all partners. IPR are only insofar part of the agreement that project members are required to set up specific agreements with one another if they deem it necessary. This decisive step towards implementation is intentionally left out of the agreement in order to allow for individual solutions.

While the general cooperation structure can be fundamental for enabling deployment, communication both within the project and to external stakeholders is another crucial factor. Different organizational structures can inhibit cooperation and thus project success. In this regard, "intense communication and joint events between partners from different sectors and disciplines help create an atmosphere of innovation and co-operation" [14, p. 33]. The physical location of the project and proximity of partners who work on campus facilitate especially informal communication channels and events as a platform for exchange. Assuming this is successful and produces deployable results, transferring solutions outside of the research environment requires yet another communication and transfer strategy. The aforementioned consultancy concept, but also business models (section 5), staff training courses by the working group on knowledge transfer and Master programs aim at different levels to ensure application.

VII. Conclusion

This paper summarized activities of the Research Campus Mobility2Grid that are aimed at implementing and transferring research results from laboratory conditions to practical application. It could be shown that fleets of electric cars as well as trucks and buses are able to contribute to a local smart grid that is fed by renewable energies. The project shows also that user acceptance can be attained under certain conditions and that various business models can be developed in this field. Since the nexus between energy and mobility is not yet an established field, new implementation concepts have to be derived. The integrated concept including technology, the human factor, and commercialization is well suited for developing such implementation concepts.

As a next step, the bidirectional charging infrastructure for the electric bus will be used to test intelligent charging and discharging algorithms. This is evaluated with regard to the provision of power system services. This is especially relevant relating to the energy transition and the fluctuating feed-in of renewable energies. The potential of car-sharing fleets was shown; a sufficiently large fleet size of electrified cars for implementation is not yet available. At least, this allows for early user involvement which is ongoing throughout the project. Business ideas are turned into business models and tested within and outside of the project. Altogether, the presented project experiences show that V2G technologies are feasible. Challenges remain with respect to economic viability outside of funding support and large-scale application of new technology options.

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