Requirements for Reliable and Flexible Smart Grids as Energy Networks in Smart Cities

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1 ABSTRACT

Whenever the characteristics of a Smart City were described, the energy sector with its power grids – the so-called Smart Grids - are considered as a crucial part and backbone of a connected urban area. In this light, an increasing number of plants in the field of renewable energies and the demands of "Sector-Coupling" and power-to-x will make intelligent networking and the exchange of energy data indispensable in the future. The almost entire amount of renewable energy facilities is feeding the distribution grid and define the challenges for its expansion. This paper will provide a synthesis regarding the aspects, which were considered as important for having effects for urban and regional planning.

The decentral energy production and consumption with the transformation from consumers to prosumers is foremost the most crucial aspect, especially in the light of the variety with renewable energy production. This means that production and consumption are preferably at the same location and the requirements for "Sector-Coupling"-facilities have to been considered. On a local scale, this means that building and urban planning requirements should foresee regulations regarding installation of energy storages on the respective scale for instance. Furthermore, the energy distribution network on local, regional and even national level and the strategic land use plans must be adapted in the way, that regulations regarding the energy network on a regional scale could also be realized in an appropriate time frame. Another important point is the necessity for handling the flexibilities in the power grid network. The power grid network and its supplying facilities has to be digitized to fit this demand and sensors as well as real-time-monitoring of the energy consumption and distribution could give useful new insights. Furthermore, the network itself has to be open and flexible in order to allow the integration of innovative solutions in the energy sector on a short- and long-term basis (Electric mobility, Smart Fabrics, Intelligent Storage Systems etc.), which could bring enormous challenges for the power grids (more flexible, more decentralized, more dynamic). All of these aspects have to be considered in the light of security and data privacy of supply in the critical infrastructures, especially for strategical planning purposes.

In order to make energy system transformation smart, cost-efficient and economically viable, several technologies and approaches regarding hard- and software must be combined: expansion and adaption of the energy network, integration of storage facilities, the use of flexibilities for prosumers and openness to new market models. All of these mentioned aspects will influence regional and urban planning on different levels regarding spatio-temporal aspects and have to evaluated carefully for the demands of a smart energy network.

Keywords: smart services, flexibility, prosumer, smart grid, smart mobility

2 INTRODUCTION

The rapid upturn in renewable energies is opening up major ecological, economic and social opportunities. However, this development poses wide-ranging challenges not only for the energy industry, but also to the electricity networks and for regional as well as urban planning in general. This is the result of an increasingly decentralized generation of the energy structure and the complexity in the planning and operation of networks itself. Ensuring the energy supply in line with the current developments (decentralization, decarbonization and information technology networking of consumption and production), solutions are required that combine offer-dependent generation with the load and storage-side flexibility for an integration in the system of renewable energies. In addition, digitization and disruptive developments will also have its effects on the built environment in the long run, especially in the light of smart and connected cities. This paper aims to provide an overview regarding the requirements for reliable and flexible smart grids for Smart Cities, especially in the context of the influences for regional and urban planning. Regarding this research question, this paper is structured in a theoretical framework, the defined challenges for realizing a smart energy grid, the resulting influences on the various scales on spatial and urban planning and a concluding section.

3 THEORETICAL FRAMEWORK

The theoretical framework gives a brief overlook regarding the characteristics of a smart energy grid with its subdivision regarding the power generation, storage and transmission and distribution. In addition, the concept of prosumers and the interdependencies between smart cities and smart grids will be explained.

3.1 Characteristics smart energy grid

It will be important to demonstrate how intelligent grids with a majority renewable energy ensure a secure and efficient energy supply and which concepts and technologies can be used for this purpose to achieve efficient and safe energy networks. Furthermore, the interaction between the distribution network and the possible business models will also be crucial to observe, especially in the light of emerging trends such as e-mobility. The core functionality of Smart Grids itself is connectivity. With their help, it is possible to connect plants, systems and devices via the Internet, regardless of location. If the systems and components involved can communicate quickly and securely, they can, for example, be combined into virtual power plants and controlled as required for instance. New services are created on this basis, which in turn can form the basis for new business models (Asmus, 2010). Tendency is going towards a decentralized energy supply, whereby the spectrum can range from power generation with wind or solar plants and combined heat, power and cooling generation to the merger of decentralized producers to virtual power plants. In order to define the three most crucial aspects, the Umweltbundesamt defines the following aspects (Umweltbundesamt, 2013).

3.1.1 Generation

Electricity production in general means the large-scale production of electrical energy with the aid of power plants. The electrical energy provided in this way is transported to the consumers via electricity grids. Besides this production, renewable energies from sources such as solar fields or photovoltaic, could also be refed into the net by sector coupling or power-to-x for instance. Sector coupling means to couple sectors of different energy domains. This method could be applied for the sectors of electricity, heating, gas, traffic and industry in general (Schaber et al., 2013). Traditionally these sectors have been considered independently but nowadays especially in smart energy grids with a heterogenous production and consumption of power, this will be one of the crucial parts of the network. This means that the overall consumption in energy networks can be decreased by sector coupling. For energy networks sector coupling also gives whole new possibilities to store energy as for instance excess electrical energy can be used by power-to-gas-plants to produce gas fuel.

3.1.2 Storage

The equilibrium of electricity in the smart grid networks and its stability is of great importance for a safe and secure energy supply. Many renewable energy sources, however, cannot simply supply electricity as required. Solar power, for example, can only be produced when the sun is shining. In this context, it is therefore so important to store electricity temporarily. Since electricity cannot be stored directly, it must be converted into another type of energy, even if this involves a loss of energy. Important storage options include reservoirs in the mountains that are linked to a pumping station. By pumping up the water, more potential energy can be supplied. The other storage option is batteries using electro-chemical processes, which allow a rapid release of electricity. Power-to-x systems are also of elementary importance in this context. Only efficient and, above all, digitally controllable storage of electricity in various storage media allows targeted transmission and distribution in the smart grid.

3.1.3 Transmission & distribution

In the energy system, transmission and distribution are the crucial part for an appropriate energy supply of electricity with the end-users. Especially in the light of the shifting majority of the energy production away from traditional power plants towards the prosumers, the importance of handling flexibilities in the network will grow. The term flexibility in this context describes the possibility of a dynamic adaptation of the generation or consumption or storage behavior by means of an external signal. A unit in which consumption and/or feed-in can be changed on the basis of external requirements. It is also defined as "deviation from a baseline". For instance a battery generally might have the flexibility to consume or to provide energy. The concrete flexibility of course relies on the mentioned baseline. If the battery is fully charged already, it cannot consume more electricity. But if its state is intermediate, the choice of consuming or providing can be described as flexibility. For a smart energy grid it is absolute essential that many participants provide those flexibilities since they allow to directly impact the state of the energy system on a local level. Thereby they particularly allow to take care of grid bottlenecks which is foremost in the interest of the network providers. The use of flexibilities therefore is considered as positive for net-serving as well as allowing also new business models. Especially since renewable energy sources have the tendency to bring a certain kind of randomness into the system (for instance the power produced by PV-plants directly depend on the weather) such grid bottlenecks might occur more often in future energy systems. If the production of a power plant is adaptable for instance and the thereby induced flexibility is matched with a flexibility emerging from a PV-plant, the potential randomness regarding the electricity production coming from the weather is absorbed. The crucial task regarding how to match flexibilities can for instance also involve further market models (by making flexibilities tradable).

3.2 The new influence of prosumers

The term "prosumer" combines the words "producer" and "consumer „and it is an artificial expression for a word for both market roles - united in one person and will be an elementary part of the energy network of the future. In the electricity sector for instance, the term describes a household customer who either consumes his self-generated electricity (e.g. from a PV system) for an own purpose and/or feeds it into the grid. If the amount of own generated energy is insufficient, he also purchases electricity from the public grid. With the gaining importance of renewable energies and the omnipresence of devices like smart meters, number of prosumers will grow, also due to the fact, that respective incentives will be set. Smart meters are digital meters that display consumption quantities and consumption times for electricity, gas and water, record this data and transmit it directly to the metering service provider and make it possible to achieve an efficient and cost-saving operation of the electricity consumption in the house on one side and for the suppliers to gather further insights to the behaviour of the customers in terms of the energy consumption. In the future, smart meters will become multi-utility communication controllers that can be used to intelligently measure water, gas and heat consumption in households. In addition, in the previous setup of the electricity network, the importance of the low-voltage-network will grow. However, the effect on the power grid itself will be a network, which is much more decentralized and thus complex in terms interdependencies of between the various levels of voltage and the origin of energy production.

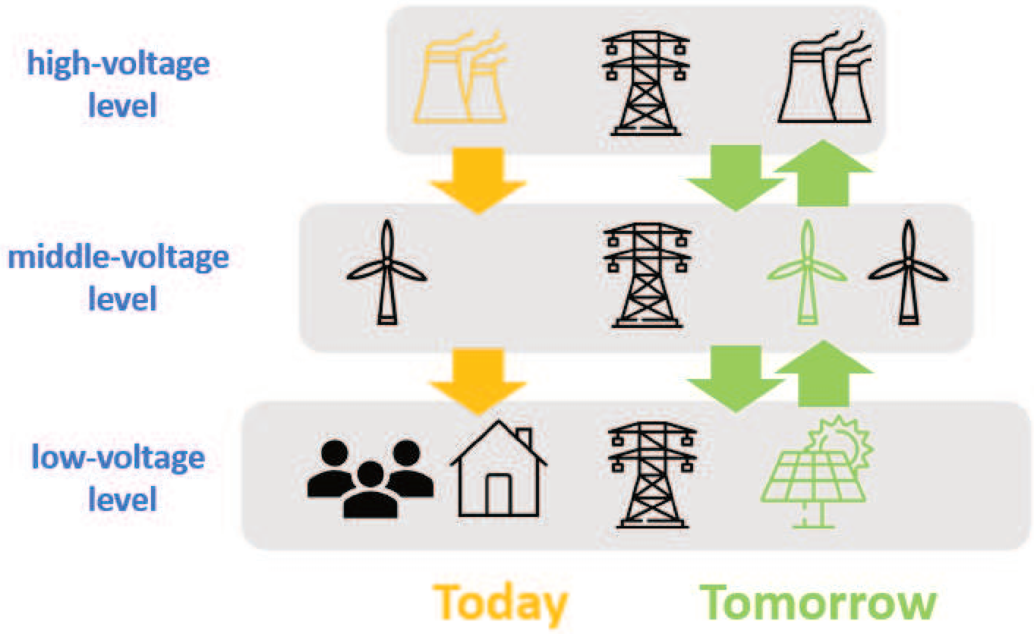

Fig. 1: Shift of energy production towards prosumers.

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3.3 Smart City in correspondence to Smart Grids

In recent years, the term smart cities has been intensively discussed in academia, as the effects of increased use of ICT in everyday life have an impact on urban and spatial planning, whereas the strategies have been widely analyzed (Caragliu, del Bo, & Nijkamp, 2011; Giffinger & Pichler-Milanović, 2007), the influence on traditional urban and regional planning in all its perspectives will be also crucial (Exner, 2013). The greatest potential in the use of networked and often centralized ICT solutions in urban areas is seen primarily in the context of efficiency increases through innovative technologies (less energy consumption, new mobility solutions, fewer emissions, less CO2 emissions, environmental pollution etc.). The underlying concept of a completely connected environment is therefore inevitably related to smart grids (Batty et al., 2012), particularly in the light of the gaining importance of terms like IoT or e-mobility. One of the potential benefits this IoT-network is seen in new insights in analysis spatio-temporal relations of real-time data-gathering as well as for predictive purposes. The advantage of this is that an immediate analysis enables direct post-steering and adjustment, for planning purposes and especially in the context of smart and connected energy networks. In the end, this approach allows, besides the efficiency effects, a more broad, dynamic, interrelated and comprehensive, understanding of a city (Kitchin, 2014).

4 CHALLENGES FOR REALIZING A SMART ENERGY GRID

One of the most far-reaching political topics in Germany which is fostering the development of a smart energy grid is the “Energiewende”. This central topic nowadays offers great ecological, economic and social opportunities. At the same time, the growing share of renewable energies in energy generation also poses enormous challenges for the energy industry. In particular, the planning and operation of energy networks and demands for e-mobility for instance is becoming much more complex due to the decentralized generation structure of renewable energies. New approaches and technologies must be developed to ensure a secure, efficient and efficient energy supply in the future which will be especially important in the areas of the generation of power, the storage and most of all in the ICT-perspective of the transmission and distribution.

4.1 Challenges regarding the characteristics of smart energy grids

The previously mentioned characteristics also induces challenges regarding the realization of smart energy grids and could be divided in three main aspects. In terms of the generation of electricity, this will be mainly in a shift of the majority from big powerplants towards various prosumers. As described in the previous sections, the integration of storage media is becoming increasingly important due to the higher share of renewable energies, especially with regard to prosumers. In addition to conventional storage options, this applies above all to power-to-x approaches as well as innovative solutions such as swarm batteries. Distribution networks and their control must also undergo fundamental changes. The infrastructure must be designed for appropriate control and adaptation functionalities and act as a resilient backbone at all levels. In addition, it is also necessary to develop appropriate platforms and market places for managing flexibilities such that the network remains as stable and efficient as possible and such that investments in conventional structures can be saved through digital network expansion in the best-case scenario.

4.2 Requirements for an open and flexible infrastructure for handling of flexibilities

As described in theoretical framework, the use of flexibilities in smart electricity network will be crucial in the future. This principle allows energy-generating units and consumers to dynamically adapt their generation, consumption or storage behavior to the needs of the energy networks or the energy market. This is particularly relevant for regions in which there are many feed-in surpluses into the network. To use them in an efficient way, the surpluses from renewable energies should be made available to possible consumers. To make optimum use of the potential for flexibilities, intelligent networking and the exchange of energy industry data is becoming increasingly important, particularly in view of the increasing number of renewable energy systems. The demands will require a network, which will be more flexible, more decentralized, more dynamic and open for potential new innovative solution. In the context of flexibility trading apart from the prosumer’s new roles such as the aggregator will acquire an increased importance. Aggregators act as marketers and can connect those who would usually do not participate in the market (e.g. prosumers who only produce little energy with PV-plants on their rooftops). To do so aggregators aggregate single flexibilities of certain prosumers to flexibilities which suit the needs of the market. To make all the processes

– especially contract closing between the single parties - which occur in such a system as transparent and efficient as possible a software system to manage flexibilities will be necessary. Apart from making information provided by the prosumers as well as process-information visible, the ability for contract closing for all parties should be possible with such a system.

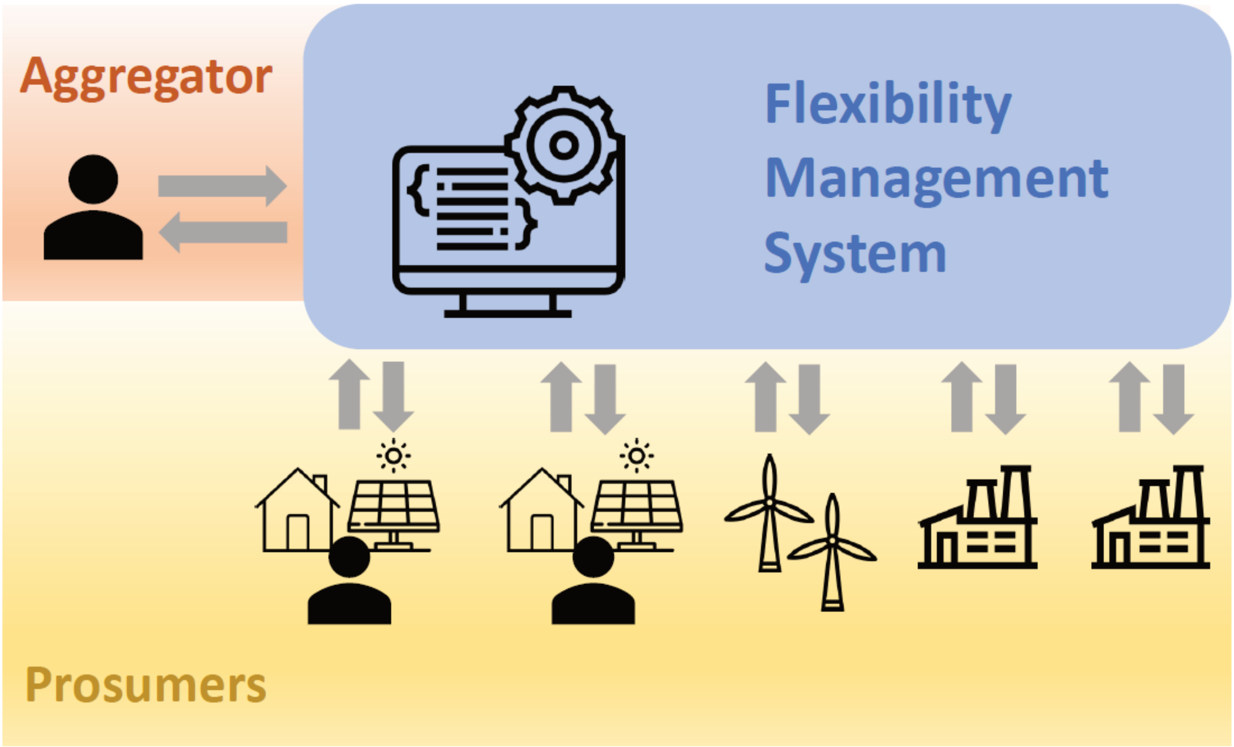

Fig. 2: Conceptual framework for a flexibility management system.

4.3 The necessity of secure and reliable networks

The vision of an ICT-based energy system of the future requires an open, widely accessible, secure, interoperable IT infrastructure as the basis. To respond to the need for a higher share of renewable energy, networks need to be extended to the specific needs with conventional and virtual net extension. These include conventional approaches such as new power plants, power lines or other investments in hardware such as battery storage. Virtual grid expansion, on the other hand, can make parts of the otherwise necessary expansion activities superfluous by making more efficient use of existing hardware capacities. Through intelligent control mechanisms from distribution nodes to smart meters in individual buildings, or even platforms for trading flexibilities, the existing infrastructure can be optimally used. The aim is to develop an integrated, uniform, open and secure data and service platform, to implement suitable procedures for managing energy data, to set up and provide a service platform for implementing energy services and to develop a solution for monitoring energy flexibility. Thus, an efficient data and flexibility management will foster an open, flexible but also secure IT infrastructure that allows data to be exchanged easily and new players and systems to be integrated. This could be implemented as the data and service platform mentioned above. The openness and accessibility perform here as a key fact for the system to gather its power. This directly induces a certain discrepancy since very sensitive information about critical infrastructure such as the network structure (including bottlenecks) are in greater danger to be accessed even by unrelated parties, yielding to security issues. To resolve the discrepancy, one has two options: Limiting the parties who can use the system or improving security standards. Using the first option only makes sense to a limited extent, such that improving security standards gains a high priority in the context of an energy-platform in general (Mo et al., 2012). Besides security aspects regarding hacking, sabotage and system vulnerabilities, the system should also include an intelligence to constantly look for potential problems (storms, catastrophes or just human error for example) with the potential for rapid insulation/capsulation. To achieve reliable and flexible smart grids as energy networks, there must be an awareness for the specific requirements on the various scales and to the various actors. There is also a demand for additional expertise, especially aspects such as

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renewable energies, digitization, virtual power plants and trading with flexibilities. The prosumer-based development and the concomitant smaller reliance from big energy suppliers will have its effects on the interdependencies overall public sector. Besides the trading of flexibilities as shown, also the use of such systems including smart meters for consumers will be crucial and must be as simple as possible. And as previously stated, the more an ICT-centric networking within the urban space is promoted, the greater the vulnerability of this system and the inherent vulnerability and manipulability to errors from an city-wide perspective (Greenfield, 2013; Kitchin, 2014; Townsend, 2013). A complex, intermodal and automated communication system must represent a resilient structure, especially with regard to internal system errors and external influences (e.g. cyber-attacks).

5 INFLUENCES ON REGIONAL AND URBAN PLANNING

The effects of a continuing expansion of smart energy networks in accordance with the previously mentioned aspects on traditional regional and urban planning are manifold and have direct and indirect effects on the various scales and phases of planning. For its role as interdisciplinary mediator of various interests in the lights of smart cities, urban planners also must be especially skilled with competences in the technological, social and institutional fields especially in the light of new developments such as smart energy networks. Besides multiple effects on evolving technical and social dynamics in the context of urban planning in general, influence towards advanced participatory formats were seen in the literature as well (Adil & Ko, 2016). The consideration could not be isolated just to ICT network, some aspects have to be realized as "real and physical" projects with the respective planning and building permit processes. Hence, the subsequent distinction regarding will show the effects on supra-local and local level planning levels.

5.1 Supra-local scale

On a supra-local level, which contains the national and the regional scale, the respective national and regional planning procedures are focus of the consideration. For instance, the further use of renewable energies will induce a demand for energy transport from regions with greater production capacity (off-shore wind parks for instance) towards areas with a locally high demand such as industrial regions. The scientific debate indicates, that wind energy offers the greatest potential for rapid and cost-efficient expansion of the energy network in national scale, especially in the light of off-shore wind parks (Weigt, 2009). Whereas areas with great wind potential mainly lies on the coast and mountainous areas, these are the locations, where wind turbines are most profitable. Besides the question of the construction legitimacy in general, the respective infrastructures for the energy transport must be realized. For instance, long distances from Schleswig-Holstein to the consumers in Baden-Württemberg and Bavaria for instance have to be installed, and the majority of the necessary lines that can handle these future electricity transports are still missing. This could lead to long-winded planning approval procedures (Planfeststellungsverfahren) and strategic developments plans, which will be a subset for further plans on lower scales. Though, the political debate has shown, that route finding for the traces could be very complicated (Krack, Köppl, & Samweber, 2017). The regional scale from a planning perspective has one focus for instance in the provision of services of public interest (öffentliche Daseinsvorsorge) which includes investments in the power grid in general such as conventional network extensions and the strategic planning of power plants for instance. The resulting requirements will also have its effects on the planning objects at this scale, such as traces or transformer substations, whether it will be for new locations or a retrofitting of existing ones. In parallel with these aspects, route finding aspect for traces will also influence the regional scale with its power supply.

5.2 Local scale

Further aspects must be also considered on the local scale which is mainly on district level and on house level with the respective procedures of urban planning as well as the building permit procedures. On this level, these are requirements for urban land use planning which will induce the installation for multimodal system stabilizers in the urban space like power-to-x-facilities for municipal utilities for instance. This is also important, because the prevention of emissions is meanwhile considered as crucial part of urban planning. The BauGB states in § 1 paragraph 5, that planning should "contribute to ensuring a decent environment, [...] promote climate protection and adaptation, especially in urban development" (dtv Verlagsgesellschaft mbH & Co. KG). Relevant projects in this perspective are for instance the potential location finding process and approval of combined heat and power plants, district-based energy storage, geothermical powerplants.

Furthermore, the impacts of the mobility sector will seriously induce some effects. This sector is considered is considered as being transferred by electrification and digitization fundamental (Mwasilu et al., 2014). This affects not only individual transport, but also public transport on a local scale as well as the interdependencies with long-distance and freight transport. E-vehicles with batteries could play their role as part a decentral storage unit for electricity in general and locally produced electricity based on renewable energies, especially for the charging supply network. New development areas or new urban development of urban districts all require a new and innovative, cascaded energy supply for the development with integration of renewable energies, storage possibilities and adequate e-mobility equipment for instance. All these aspects rely on the requirements of the local urban land-use planning and building regulations, which should also foresee professional and tailor-made solutions. One other aspect is the physical integration of the required charging infrastructure in the urban space. It is clear, that the existing petrol station network cannot be entirely utilized for this purpose. Also the question of the location of charging points in accordance with the corresponding parking facilities will play a crucial role in the design of the streetscape of the future. This will be especially important in the light of location finding process regarding local mobility points for car-sharing. And if the areas of petrol station could be partially used, what are useful post-utilizations for those areas? Furthermore, question like the location power-to-x facilities as well as batteries with respective security constraints or challenges of the local net voltage by fast chargers for e-cars are also open questions. On the other hand, totally new approaches like mobile charging stations (proposed by Volkswagen for instance) or changing points for modular batterie (fist concepts by Toyota) will also induce in their way set in part completely different demands for the urban infrastructure, which must be as modular, granular and flexible as possible. In addition to the district perspective, the building perspective especially in the light of local building code and authorization procedures. Crucial parts in this perspective are especially the integration of battery storages in buildings or the respective voltage lines to charge e-mobility cars to fit the demands of in-house charging for e-vehicles.

6 CONCLUSION

The new challenges regarding smart grids influence a wide range of tasks in regional and urban planning activities. In the context of smart grids, it will be crucial, to manage the expansion and adaption of the energy network, the integration of storage facilities, and to ensure the flexibility for prosumers and openness to new market models. Hence, if a “digital extension” of the electricity network to achieve a higher efficiency will not be enough, respective solutions in terms of hardware should be foreseen in formal urban planning tools on the respective scale. One general aspect in terms of energy efficiency will be, to combine local production and consumption of electricity on the smallest possible scale. In addition, the demands on the emerging e-mobility beside the grid-side perspective could have extensive influences on the urban area. General question concerning the general model of transport (more public transport, more individualized, more car-sharing) have their own demands for the design of the urban space and the corresponding connection to the electricity network. In this way, the design of a mobility concept is inseparably connected to the design of a Smart Grid in the light of a Smart City. Consequently, planners have to be aware, that even concepts on a programmatic level could induce the built structure of a city on a large scale and it is important to accomplish this also with the relating formal building laws. In order to achieve this, regional and urban planners have to enhance their competences and awareness for the previously shown topics and the key to achieve reliable and flexible smart grids will not be a one-fits-it-all-solution but more a decent subset of tools and approaches tailored on the particular situation.

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Further information under www.designetz.de

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