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Relying on storage or ICT? How to maintain low voltage grids' stability with an increasing feed-in of fluctuating renewable energy sources

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**Relying on Storage or ICT? How to maintain low voltage grids' stability
with an increasing feed-in of fluctuating renewable energy sources**

Abstract: Since the beginning of the new century our electricity system is changing rapidly. Distributed energy resources, such as wind or solar energies are becoming more and more important. These energies are producing fluctuating electricity, which is fed into low voltage distribution grids. The resulting volatility complicates the exact balancing of demand and supply. These changes can lead to distribution grid instabilities, damages of electronic devices or even power outages and might therefore end in deadweight losses affecting all electricity users. A concept to tackle this challenge is matching demand with supply in real-time, which is known as smart grids. In this study, we focus on two smart grids' key components: decentralized electricity storages and smart meters.

The aim of this study is to provide new insights concerning the low diffusion of smart meters and decentralized electricity storages and to examine whether we are facing situations of positive externalities. During our study we conducted eight in-depth expert interviews.

Our findings show that the diffusion of smart meters as well as decentralized electricity storages is widely seen as beneficial to society. This study identifies the most important stakeholders and various related private costs and benefits. As private benefits are numerous but widely distributed among distinct players, we argue that we face situations of positive externalities and thus societal desirable actions are omitted. We identify and discuss measures to foster diffusion of the two studied smart grid key components. Surprisingly, we find that direct interventions like subsidies are mostly not seen as appropriate even by experts from industries that would directly benefit from them. As the most important point, we identified well-designed and clearly defined regulatory and legal frameworks that are free of contradictions.

JEL codes: O13, O33, Q21, Q41, H23, L50

Keywords: smart meter, decentralized electricity storage, smart grid, externality

1 Introduction

Energy markets are rapidly changing and will lead to a transformation of our electricity system. Conventional energies (e.g. coal, nuclear) will be increasingly substituted by fluctuating renewable energies (e.g. wind, solar). A lot of this energy will be fed into the low voltage electricity grid. As periodically fluctuating consumption is met with weather-dependent production, the exact balancing of demand and supply [1] already is and will become a complex challenge. This issue has to be tackled within the coming decades [2]. Renewable energy production e.g. in Germany is already approaching 20% of net electricity production [3]. The recently agreed nuclear phase-out until 2022 is accelerating this development [4]. Therefore this challenge has to be tackled within the next five to ten years. We therefore focus on Germany, even though many of the results are of general nature and can be applied to other electricity systems which are about to change due to an increasing use of renewable energies.

Smart grids are seen as a solution to the challenge of matching fluctuating production and demand. Policy makers, practitioners, and researchers focus intensively on smart grid infrastructures as energy systems impact on society and economy is enormous. The exact architecture of future smart grids is still unclear, but smart meters as well as decentralized electricity storages will be important components [5]. Using additional near-to-real-time information from smart meters can improve and optimize the way electricity is generated, distributed and consumed [6]. As smart meters are seen as a core component to enable the realization of expected benefits of smart grids, many countries around the world are investing heavily in the rollout [7-10]. Required investments are estimated to be enormous: Faruqi et al. estimate an investment of €51 billion for the European Union [8]. While technically a rollout of smart meters during the next decade is regarded as possible, it is not yet clear to all stakeholders involved how the evolution to smart grids is going to take place in practice [11].

Besides the information-based approach using smart meters, electricity storages can buffer excess energy, balance supply and demand, and thus increase the amount of renewables that can be installed without risking instabilities [12]. In order to fully shift to renewables it is estimated that Germany needs to increase its storage capacity by a factor of 500 [4]. As in the case of smart meters, even though technically possible, it is not yet clear how the diffusion of many storage facilities can develop, who the most important actors are and which part they will play in a solution.

Hammons presents different possible system architectures for an integration of renewables into European electricity grids [13]. In these, decentralized electricity storages and smart meters play an important role. According to Ipakchi and Albuyeh especially in the distribution grid the two components are huge issues [14]. Thus, in this study, we focus on how the diffusion of these two smart grids' key enablers can be fostered and how renewables can be integrated more effectively.

Previous research has not yet fully solved the question of how to maintain low voltage grids' stability with an increasing feed-in of fluctuating renewable energy sources. In specific, an appropriate path of implementing smart metering and/or decentralized electricity storages has not yet been identified. Thus, it is not clear how the energy system can evolve into a smart grid.

Our explorative research makes the following contributions: first, we identify stakeholders and discuss their opportunities and risks. Second, we provide new insights on smart meters' and decentralized electricity storages' low diffusion. Our results are derived from qualitative interviews with industry experts and give an understanding of their assessments and strategies. Third, we study whether there are situations of positive externalities in smart grids' emergence and whether new incentives and regulatory intervention are necessary. Last, we identify important questions to be addressed by further research.

The remainder of this article is organized as follows: In section 2 we review related literature. Section 3 gives an overview of the theoretical concept of externalities. In section 4 we explain the applied methodology. Section 5 presents our qualitative study, the sample, the data collection and data analysis. In section 6 we show our findings and results of this study. Section 7 gives a conclusion and discusses managerial and political implications. Furthermore, in section 8 limitations of this study are discussed and avenues for further research are outlined.

2 Related Literature

2.1 Decentralized Electricity Storages

Given that the construction of large scale pump storages is politically neither locally nor nationally possible and economically reasonable, new kinds of electricity storages are necessary [15]. The function of electricity storages is to temporally decouple generation and consumption. There is a wide range of technologies for electricity storages and diverse applications. An overview is given in the following:

Storing electricity can either be done directly by storing electrical energy (e.g. in capacitors) or indirectly by conversion to mechanical-potential energy (e.g. pumped hydro storage, compressed air), mechanical-kinetic energy (e.g. flywheels) or electrochemical energy (e.g. lead acid battery, lithium ion accumulator, redox-flow-batteries, hydrogen storage). If stored indirectly, the energy has to be reconverted into electricity before utilization. In literature the term energy storage is sometimes also used for load management (e.g. demand side management), which is then called virtual energy storage. We exclude virtual energy storage

from our analysis and focus on physical storage. An overview of different electricity storage technologies is given in figure 1.

Energy Storage Technologies				
Form of energy	Mechanical energy (kinetic or potential)	Electrochemical energy	Electrical energy	Virtual energy
Examples	<ul style="list-style-type: none"> • Pumped hydro storage • Compressed air storage • Flywheel 	<ul style="list-style-type: none"> • Hydrogen • Batteries: <ul style="list-style-type: none"> • Lead acid • Nickel cadmium • Nickel metal hybride • Lithium-ion • Sodium-sulfur • Redox-flow <ul style="list-style-type: none"> • Vanadium • Zinc-bromine 	<ul style="list-style-type: none"> • Super-conducting coil • Electro-chemical double layer capacitor 	<ul style="list-style-type: none"> • Demand Side Management • Demand Response • Thermal storage
Physical storage				Non-physical storage

**Figure 1: Energy storage technologies
(Based on [15] p. 521)**

Energy storages can also be distinguished with regard to their application and related power. There are four types of storages: Central storage power plants¹ are connected to the high voltage grid, decentralized huge battery storages² are connected to the high and medium voltage grid, local small storages are connected to the low voltage grid and short-time storages³, which are used to increase power quality. Even though a high need for increased capacity of electricity storages is anticipated, it is not clear if the lion's share will consist of centralized or decentralized storage systems [16]. In this paper the focus lies on local small storages as we address issues of low voltage grids' stability. Local small storages have power

¹ Centralized storage power plants have power outputs over 100 MW. The usually applied technology is pumped hydro. In rare cases other technologies, like compressed air or hydrogen are in use as well.

² Decentralized huge battery systems have power outputs of one to 100 MW. Usually applied technologies are lead acid, nickel cadmium, sodium-sulfur and redox-flow.

³ Short-time storages can have a wide range of power outputs in the magnitude of W to MW, but all of them have only small capacities (kWh). Usually applied technologies are flywheels and double layer capacitors.

outputs of one kW to some 100 kW. Usually applied technologies are lead acid, nickel cadmium, nickel metal hybrid and lithium-ion batteries [15].

In order to improve the integration of renewables into the low voltage grid, local small storage systems can either be installed close to prosumers (combination of a consumer and a producer [17])⁴ or directly at prosumers, e.g. in the basement of households [18].

Previous research has mainly dealt with technical issues of integrating decentralized storage systems into electricity grids [19, 20], their impact on power system stability [21], arbitrage value of storage devices in specific regions [22] or specific applications, like wind farm repowering projects or island systems [12]. Furthermore there is research on specific incentive methods for electricity storage systems, like the compensation for self-consumption of electricity produced by photovoltaic systems [18].

2.2 Smart Metering

Smart metering technology includes an electronic meter in combination with an advanced metering management system and metering infrastructure [10, 23-25]. Therefore the following tasks can be achieved: first, the measurement and recording of usage data in real time, second giving customers the possibility to participate in demand response programs and third, the supply of data to monitor the voltage and facilitate other service issues [6].

Smart meters are central gateways located on the customers' site which support bidirectional communication. Thus, smart meters bridge the communication gap between consumers and other energy systems' parties by means of information and communication technologies [6].

The new metering infrastructure is, for example, essential for energy efficiency measures, monitoring and management of grids, load balancing and shifting [23]. Thus, smart metering technology facilitates more transparency in information exchange and allows more efficient and anticipatory coordination between power generation and consumption [26]. In

⁴ A prosumers can be for example a household with an installed photovoltaic system on the rooftop.

comparison to regular meters, smart meters are also able to show detailed information concerning the consumption in almost real time and allow for direct feedback to adjust demand. Previous research has mainly dealt with technological issues with regard to smart meters [27]. However recently, research dealt with consumer-related issues. Some studies, for example, analyzed acceptance of consumers concerning smart meter technology (e.g. [6]). Other research focused on benefits of smart metering technology (e.g. [24]) or focused on solutions that are enhanced by information systems like green information systems to address environmental sustainability (e.g. [28-32]). Furthermore, lots of research focused on regulatory factors concerning the energy market and smart metering (e.g. [10, 33-35]). Some research identified that environmental concern is positively linked to the adoption of eco-innovations [36]. Yang et al. identified that in a smart metering scheme, suppliers, estate managers and consumers are direct contributors [26]. In Germany, electric power companies have to install smart meters in new buildings since 2010 [37]. Thus, according to Böning et al. the increasing use of smart meters is more due to regulation than due to industry initiatives [38]. Other research found that replacing standard meters with smart meters leads to a decrease in electricity consumption of up to 20% [39] or identified that smart meters are an appropriate way against electricity thefts [40].

3 Theoretical Framework

This study focuses on understanding the slow diffusion of smart meters and decentralized electricity storages. As a theoretical framework we use the concept of externalities within the theory of transaction costs and property rights. Property rights theory deals with the design and allocation of actor's rights to use a good. Transaction cost theory is concerned with costs to transfer property rights from one actor to another [41].

In this study we focus in detail on positive externalities, a specific form of an external effect.

In the following we give an overview of the concept of externalities.

There are consumption externalities as well as production externalities [42]. Graaff defines externalities as follows: “External effects exist in consumption whenever the shape or position of a man’s indifference curve depends on the consumption of other men.” [43, p.43]. External effects in production “are present whenever a firm’s production function depends in some way on the amounts of the inputs or outputs of another firm.” [43, p.18] According to Buchanan and Stubblebine this is a typical definition of externalities [44]. In this study consumption as well as production externalities are considered. As there is no reason for a separate discussion of production and consumption externalities in this study we use the general term individual as it is used by Buchanan and Stubblebine [44]. Both situations can create problems and may result in non-Pareto-efficient outcomes. These Pareto-relevant externalities are usually meant by economists using the term externality. Every individual is only optimizing his own private benefit. As individuals do not take into account effects of their actions on others, thus social costs and benefits, welfare is not maximized [44]. There is another way to distinguish externalities: Situations can have negative or positive externalities [42]. In general economic theory negative externalities are defined as an action of one individual that has negative effects to at least one other individual. Such situations can result in actions even though they are inefficient on a social scale. Positive externalities are defined as an action of one individual that has positive effects to at least one other individual. [41,42]. For the purpose of this study whenever we refer to the term positive externality we consider only a subsection of positive externalities which is defined as the sum of social and private benefits exceeding its private costs, with private benefits smaller than private costs, in other words an economically unattainable situation. A situation like this can lead to the omission of an action, which is in general desired by society (see figure 2) [41, 42]. This study focuses on these specific positive externalities. We analyze situations, where benefits for individuals

might be too small to perform an action even though benefits for the society as a whole would be huge.

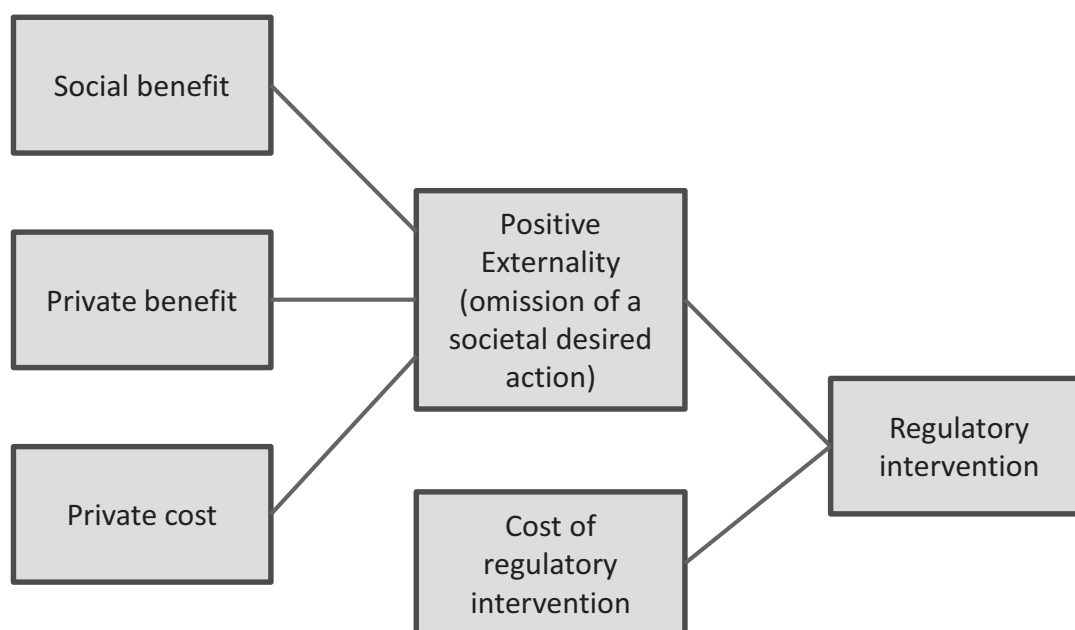


Figure 2: Illustration of the theoretical framework and relations between variables in the concept of positive externalities and regulatory interventions

4 Method and Procedure

To explore fundamental research questions in a new research field such as smart grids, qualitative research is an adequate method as traditional data collection methods are inappropriate [45]. Furthermore, qualitative research is an established methodology in science and finds specific application in marketing and social sciences [46]. Other studies concerning smart grids and in particular the smart metering technology have also relied on qualitative research (e.g. [47]). Hence, to answer the research questions in this study, we make use of the qualitative interview technique conducting and analyzing expert interviews.

4.1 Sample

In our study we focus on the German market. We performed eight in-depth interviews with German experts. In order to interview a varied pool of participants, we conducted the interviews with experts from different industrial sectors [48]. We recruited the experts by using direct contacts, addressing them on conferences and fairs as well as via secondary contacts. The interviewed experts work in executing positions or prepare decisions in leading organizations, thus having an extensive knowledge of the research field. In our sample are experts from different hierarchy level. Table 1 gives an overview of the participants in this study.

1	Managing Director of a Venture Capital and Private Equity company
2	Manager for strategy and business development in a large telecommunication company
3	Scientist in a leading position of a policy-consultancy in the field of technology assessment and energy markets
4	Chief executive officer of a consultancy specialized on utilities
5	Manager for the development of systems integrating solar systems and electricity storages
6	Manager for the telecommunications department of a large German public utility
7	Team leader for the development of a small-scale electricity storage system
8	Project manager for a German e-Energy ⁵ model region

Table 1: Overview of interviewed participants

4.2 Data Collection

To answer the research questions, we use the qualitative interview technique interviewing experts. We conducted each interview separately (one-to-one). The interviews lasted between 35 and 90 minutes. Interviews were conducted face-to-face as well as via telephone. The combination of face-to-face and telephone based interviews is adequate and was applied in other studies (e.g. [49, 50]). The interviews were semi-structured, using an interview guideline that was prepared on the basis of theoretical considerations. Thus, we had the

⁵ E-Energy is a funding programme of the German Federal Ministry of Economics and Technology (BMWi) and the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU).

possibility for discussions and additional questions [51]. A pretest for the interview was performed to evaluate the first version of the interview guideline and to optimize accordingly. With the interview invitations, we sent an overview on this study's topic. At the beginning of each interview, we introduced ourselves and explained the goal of this research before asking the interviewee on his/her position, current work and experiences in the field of research. We developed the interview guideline to ensure consistency and adopted the interviews to leverage the respective expertise and background of each individual. This procedure together with additional questions arising out of the situation allowed a natural course of conversation. The aim of the interviews was to inquire the experts' view on the value and diffusion of both technologies smart metering and energy storage. Interviewees were asked about their evaluation of the economic value of a widespread use of these technologies and reasons for the current weak diffusion. Moreover, we asked which stakeholders they see most engaged with the two components and which players have the players' costs and benefits of a wide implementation would be. Furthermore, they were asked for possible incentives to foster implementation of both technologies and how regulatory intervention could look like. After six interviews we realized that only few new aspects were emerging during the interviews, which we identified as a saturation concerning the research topic [46]. In total we conducted eight interviews with experts, which is in line with McCracken [52].

4.3 Data Analysis

There are different approaches how to analyze qualitative interview data (cf. [53-55]). The methodology proposed by Glaser and Strauss aims at the generation of theory (Grounded Theory) [53]. Spiggle focused on evaluating interviews conducted with consumers [54]. For our analysis, we used an approach by Mayring [55, 56], as it is widely used in literature of related research fields (cf. [57-60]).

More exactly, we used the structured content analysis suggested by Mayring for semi-structured interviews. This approach aims at filtering certain aspects of the collected material and evaluating it in terms of certain criteria. Several steps are recommended [55], which we applied on our analysis and which we will describe in the following.

The interviews were taped and verbatim transcribed at full length [61]. As the interviews were conducted in German, we first transcribed them into German text. In the further analysis we translated results and findings into English using constant contextual comparisons during the analysis [62].

Afterwards the interviews were paraphrased and shortened, while keeping the original text's sequence. The material was then sorted in two structuring dimensions, the two considered technologies according to the interview guideline. In a following step we derived a category system out of the theoretical framework and our research questions. The categories were clearly defined. We annotated a typical example to each category and agreed on coding rules to achieve a correct classification of the interviewees' statements. This is an established procedure of categorization [55, 56]. In the next steps we first passed through the material coding statements by marking certain text passages and second rearranging them topic-wise, in order to facilitate an easy comparison and interpretation. During this process coded transcripts were checked for appropriateness by the authors and coding rules were adapted accordingly. Statements of single experts that we used to illustrate our findings are not put in quotation marks, as they are no literal citations due to translation. Instead we indented the statements. To some extent findings were put together in tables. As a last step we refined and finalized results and findings.

5 Findings

5.1 Smart Meters

In this section we discuss general social benefits that arise from the utilization of smart meters. Second, we present the most important stakeholders and private benefits and costs for each of them. In the third part we look at measures to foster the diffusion of smart meters.

5.1.1 Discussion of Social Benefits of a widespread Use of Smart Meters

Our analysis shows that generally a nationwide diffusion of smart meters is seen as economically desirable by the majority of interviewed experts.

A widespread use of smart meters is desirable in order to increase transparency and competition in the electricity market. – Manager for strategy and business development in a large telecommunication company

Our market view is that a mass rollout is economically reasonable. – CEO of a consultancy specialized on utilities

Diverse reasons were mentioned. In a micro level perspective many benefits for different stakeholders could be identified which will be presented in the following section. On a macro level experts see the chance for increased transparency and competition as well as better monitoring and control opportunities to maintain stability of the electricity grid. Some benefits can only be realized in a mass rollout like an improvement of balancing and process efficiencies on the utility side. Therefore, the hypothesis arose that smart meters should either not being installed at all or rolled-out massively.

Even though the majority of interviewed experts are in favor of a rollout, some do not have a clear opinion yet. Before investing, they see the need for an in-depth cost-benefit analysis and a better understanding of private and commercial end-users' reactions on variable tariffs.

Although the overall view on a rollout is positive, one expert argued against it with the reason that end-users' savings being too small not outweighing the high costs of smart meters.

5.1.2 Identified Stakeholders and their Smart Metering related Costs and Benefits

The most important stakeholders concerning the implementation of smart meters that we identified and assessed in the interviews are distribution system operators, private and commercial end-users that could have own electricity production (“prosumers”), electricity retailers, metering service providers and metering point operators, telecommunication companies, private and public utilities as well as new market entrants. In addition to the stakeholders we identified many benefits, advantages and opportunities that could be realized due to smart meters as well as costs, disadvantages and risks for each of the actors. As smart meters provide measuring data and this information can then be used by various players, relations are manifold and complex.

Smart meters are at first just a measuring system. Just having the information itself is not a created value. Not until someone is processing and using the data, thus, creating value, it starts getting interesting. – Team leader for the development of a small-scale electricity storage system

In order to shed light on the diversity of effects and impacts of smart metering on distinct stakeholders we put together a clearly arranged table (see figure 3). Private costs (see grey boxes below) and benefits (see white boxes below) are allocated to corresponding players. For reasons of clarity private as well as commercial end-users with or without an own electricity production have been merged under the term end-user. Furthermore, costs and benefits that were mentioned for smart metering service providers appear in the row of the metering point operator. Other actors that have been mentioned are the automotive industry due to an expected increasing amount of electric vehicles, energy wholesale market, energy exchange and traders, responsible organizations for balancing groups, manufacturers of electronic components (e.g. smart meters, plugs, cables, photovoltaic and storage systems). As those are not seen as key stakeholders by a majority of the interviewees, we have not included them in figure 3.

Identified Key Players In Smart Meter Market	Distribution System Operator	Better Grid Load Management			Higher Grid Stability Due To Predictions			Save Expenses For Grid Expansions			
	End-user	Service Quality Increase	Lower Electricity Expenses	Time Or Load Variable Tariffs	Transpar. Electricity Bill	Visualiz. And Control	Improv. In Energy Efficiency	Load Shift Out Of Peak-times	Value-added Services	High Installation Costs	Reduced Economic Life-time Of Meter
	Electricity Retailer	Simplified Meter Reading	Possibility To Offer Special Tariffs	Improv. In Customer Retention	Competit. Advantage	Cheaper Procurement	Less Billing Errors	Reduction Of Non-technical Grid Losses	Additional Costs, If Involved In Installation	Risk For Dominant Players (Transp.)	Billing Accord. To Stand. Load Profiles
	Metering Point Operator	Income Due To Fees For Metering Service		Cost Reduction For Meter Reading		Handling Of Immense Data Volumes		In Transition Period: Two Different Meter Reading Systems in Parallel Necessary			
	New Market Entrants	New Business Models		Special Offers From Niche Players		Enabling Of Value Added Services		Bundling And Coordination Of Power Consumers			
	Tele-communication Companies	Opportunities, If Involved In Data Transfer	New Market Similar To An Existing One	New Fields Of Applications In B2B And B2C Area		Opportunities Due To Cooperation With Utilities	Operation Of Huge Data Centers	Possibility To Enter The Electricity Trading Market	Risk Due To New Communication Access Point		
	Utilities (Private/Public)	Reduction Of Overcapacities					Price Transparency Threatens To Loose Market Dominant Position				

Figure 3: Key stakeholders in the smart meter market and their private costs and benefits

Most important drawbacks of smart meters are high investments⁶ besides uncertainties, risks and transition problems. These private costs of stakeholders are contrasted by numerous advantages and opportunities widely spread over all players. This picture clearly indicates situations of positive externalities: On the one hand, as argued above, smart meters are generally seen as beneficial for our society, also reflected by the huge amount of identified private benefits. On the other hand, we see a low diffusion of smart meters as high investments for implementation are not outweighed by private benefits for any of the single stakeholders which leads to the omission of an action which is seen as beneficial for society.

5.1.3 Measures to foster Diffusion of Smart Meters

To overcome barriers of a wide diffusion of smart meters a set of measures and approaches to foster implementation of smart meters were identified. These are discussed in the following.

⁶ Investments for smart meters will presumably appear on end-users' or electricity retailers' accounts.

Well-designed legal requirements and regulatory frameworks are seen as an appropriate way. They have to be clearly defined and free of contradictions, which is not the case up to now. These points were often mentioned and display the most important points.

Out of the interviews we further identified that standardization, for example in the case of interfaces, is an appropriate way to overcome obstacle. Standards have to be defined to enable a modular design of smart meters. This would allow changes and supplements to once installed smart meters and thus decrease the risk of expensive replacements.

Under the condition that a cost-benefit analysis leads to the result, that we have the wish to introduce smart meters nationwide, regulatory interventions would be necessary. – Scientist in a leading position of a policy-consultancy in the field of technology assessment and energy markets

We also find that specific loan programs can be used to foster the diffusion. In this context niche players need to get an easier entry to the market. Companies entering the market with an innovative pricing model could be subsidized by the government and end-users can be motivated to acquire a smart meter by receiving subsidies. All in all smart meters need to be offered to the end-user for free or a very low price. Surprisingly, direct interventions using subsidies or tax releases were not seen as a useful measure from most industry experts.

Subsidies, in the sense I pay something so that he/she is doing it, what he/she would not do by his/herself, I think, this cannot be the right way. CEO of a consultancy specialized on utilities

Showing customers how they benefit from smart meters for example from cost savings due to lower reading costs, more transparency, recognition of electricity guzzlers as well as lower electricity costs in times of excess energy in the grid should be moved into the foreground. Insufficient illustration and communication of advantages to end-users have been mentioned as a crucial weakness.

5.2 Decentralized Electricity Storages

This chapter focuses on decentralized electricity storages. First, we discuss the general social benefits resulting from an implementation of decentralized storage systems. Second, most important stakeholders and identified private benefits and costs for each of them are presented. In the third part we look at measures to foster the diffusion of decentralized electricity storages.

5.2.1 Discussion of Social Benefits of a widespread Use of Decentralized Electricity Storages

Implementation of decentralized electricity storages is generally seen as having a high value for society. Battery systems are seen as an important factor, especially for the integration of wind and solar energy. Further reasons that were mentioned are the possibility to avoid energy losses from electricity transmission over long distances⁷ and the insufficient potential of pumped hydro. Especially between households and distribution system operators a win-win situation could evolve. None of the interviewees mentioned that decentralized electricity storages are not economically desirable in general, even though one interviewee was indecisive and sees initially the need for further research. The approach of decentralized electricity storages could in particular be compared to a high degree of load management, gas-fired power plants and the approach to balance supraregional in order to benefit from stochastic effects. However, although seven out of eight experts argue in favor of decentralized storage systems, on a closer look opinions are not that similar anymore. On the one hand given answers differ in terms of the estimated time frame for decentralized storage systems to get implemented in great quantities. Views range from next year over more than five years to still undefined:

Excess electricity is an economic problem. Electricity storages separate the up to now necessary symmetry and simultaneity of consumption and production. From next year

⁷ This benefit has to be weighed against energy losses from the limited electricity storage efficiency.

on many decentralized storage systems will be brought to market and installed. – Team leader for the development of a small-scale electricity storage system

I believe that decentralized storages will come to supplement decentralized generation from renewables. However, the topic is not that far developed as the field of smart metering and I do not think that an economical applicability will be reached earlier than in five to ten years from now. – CEO of a consultancy specialized on utilities

First, it need to be analyzed if balancing of supply and demand could not be organized in a more efficient way by load management or using regional gas-fired power plants. – Scientist in a leading position of a policy-consultancy in the field of technology assessment and energy markets

On the other hand a project manager of a German e-Energy model region mentioned that implementation of decentralized electricity storages is desirable in general, but not necessarily nationwide.

Decentralized electricity storages should be installed at specific points, where they create especially high benefits. For example if it possible to avoid grid expansion. – Project manager of a German e-Energy model region

Furthermore, the majority of interviewees regard the field of decentralized storage systems as not sufficiently developed at the moment. Research is needed as battery technologies are still not sufficiently efficient and working business models are to be developed.

With integrated business models and tariff-based incentives decentralized electricity storages turn out to be an interesting concept. I consider it as economically reasonable. – Manager for the development of systems integrating solar systems and electricity storages

5.2.2 Private Costs and Benefits related to Decentralized Electricity Storage

The identified most important stakeholders concerning the implementation of decentralized electricity storages turned out to be the same players as in the case of smart meters. For this part other mentioned actors that are not equally important are players in the reserve energy market, manufacturers of electronic components, research and development companies and the energy exchange operator. However, even though identified key stakeholders are the same as above, compiled opportunities, advantages, risks and disadvantages are different. Again high investments play a huge role as batteries are very costly in comparison with for example

pumped hydro plants. As consequence of high battery costs storage systems for prosumers usually are dimensioned in a way they cannot provide autarchy.

If you have a 10 kWp photovoltaic system on your roof and then you install for example a 10 kWh lithium-ion storage system - with today's prices this would cost more than 12000 Euro. However, when the sun is shining such a system would be fully charged after only one hour. When charging with full power at ten o'clock in the morning, the battery is full at eleven o'clock. Then produced electricity has to be fed into the grid or the solar system has to be switched off. – Manager for the development of systems integrating solar systems and electricity storages

Other private costs are energy losses due to low storage efficiencies. Furthermore, for electricity retailers and utilities, decentralized electricity storages at end-users' can lead to considerable disadvantages as electricity sales might decrease and storage-equipped prosumers could act as competitors to gas-fired power plants.

These private costs of diverse players are contrasted by manifold benefits that emerge for distinct actors. As one would expect many of the benefits appear for the end-users where decentralized electricity storages can be installed. Another player benefiting widely is the distribution system operator.

I see the value added especially when it is possible to take pressure off and stabilize the low voltage grid – more than on end-user side. – Project manager of a German e-Energy model region

Furthermore, a widespread implementation of decentralized electricity storages would provide number of chances and opportunities for new market entrants.

An overview of identified key stakeholders and related private benefits and costs is given in figure 4. Identified actors that have been classified as not being key stakeholders do not appear in figure 4.

Our findings indicate the danger of emerging situations of positive externalities in the future. As presented above decentralized electricity storages are generally seen as beneficial for our society even though an implementation may not be recommendable earlier than in a few years from now. Anyhow, a low diffusion of decentralized electricity storages is foreseeable, as benefits are spread over many players. As long as not enough benefits are concentrated on one

single actor and thus private benefits not being able to outweigh private costs, the omission of the socially desired action to invest in decentralized electricity storages is probable.

When always only considering decentralized electricity storages isolated from one perspective then one will not go very far. – I, as distribution system operator do not see a profitable investment. I, as electricity trader, do not see a profitable investment. Then one will not go very far. When considering decentralized electricity storages jointly it is something else. But there are a lot of open questions. Is it allowed? How does it look like? There is still a lot to do in the field of decentralized electricity storages concerning laws and regulations. – Project manager of a German e-Energy model region

Identified Key Players In Market For Decentralized Elec. Storages	Distribution System Operator	Improved Grid Stability - Control Of Frequ./Voltage	Peak Shaving (Avoidance Of Grid Expansion)	Load Shifting (Temporal And Spatial)	Increase In Availability And Grid Utilization	New Business Fields	Pooling Of Distributed Electricity Storages	High Investment			
	End-user	Optimize Income From Produced Electricity	Influence The Own Energy Mix	Maximize Feed-in Compensation	Hedging Against Increasing Electricity Prices	Cost Reduction Due To Peak Shaving	Feeling Of Autonomy / Battery Backup	Possibility To Disconnect from Grid	Low Storage Efficiencies	Storages Too Small For Autarchy	High Investment
	Electricity Retailer	New Business Field To Offer A Combination Of Photovoltaic Systems And Storage Systems Together With Attractive Tariffs					Reduction In Electricity Sales Due To A Higher Self-consumption Of Prosumers				
	Metering Point Operator	New Business Fields (E.G. Transparency, Calculation And Billing Of Variable Tariffs, Self-consumption Tariffs, Locally Produced Electricity)									
	New Market Entrants	New Business Models suppl. Traditional Core Business	Provision Of Forecast Data	Provision Of Solutions For Demand Side Management	Provision Of New Grid Control Methods	Opportunities For Value Added Services	Solutions For The Data Integration Into Company Processes				
	Tele-communication Companies	New Business Fields (E.G. Providing The Connection From Utility To Storage Systems In Households, Communication Of Real-time Price Signals)									
	Utilities (Private/Public)	Enabler For New Business Models (e.g. Virtual Power Plants)	Cooperation With Households To Have Remote Power Control For Reserve Energy			Competition For Certain Power Generation Facilities (e.g. Gas-fired)			High Investment When Owning Distributed Electricity Storages		

Figure 4: Key stakeholders in the market for decentralized electricity storages and their private costs and benefits

5.2.3 Measures to foster Diffusion of Decentralized Electricity Storages

In the following measures and approaches to boost diffusion of decentralized electricity storages are presented. We find that monetary incentives can be an effective measure for promoting the installation of decentralized electricity storages. Additionally, new price mechanisms to compensate for feed-in and self-consumption of renewably generated electricity as well as smarter tariffs were identified as possible measures. The interviewees

often mentioned that more research has to be conducted to develop more efficient batteries. Another way lies in encouraging and boosting own internal electricity consumption (self-consumption). A wider diffusion would lead to an increase in sales and production numbers which would imply the decrease of costs for storages (economics of scale and learning curve). Furthermore, we identified that performance-based feed-in compensation can be an appropriate way fostering diffusion. Thus making compensation (in Euro per kWh) dependent of feed-in power makes peak-shaving and the use of decentralized electricity storages financially compelling. Here, an incentive would be to decrease the compensation by increasing feed-in power.

It is not the business of legislature to substitute the creativity of markets. – Team leader for the development of a small-scale electricity storage system

Regulatory interventions are seen as an important adjustable screw, because energy demand has to be met in the future in particular with an increase of renewables. Others are more skeptical concerning regulatory interventions.

6 Conclusions and Implications

Increasing use of decentralized energy resources, like wind or solar energy, will lead to a growing amount of fluctuating electricity production. Low voltage grids' stability is threatened if constant demand patterns are met with fluctuating production. Against this background, our study evaluated social benefits of smart meters and decentralized electricity storages which allows for real-time adjustments of demand or intertemporal delinkage of supply and demand. Utilization of these two components is an appropriate way to cope with this growing risk. Experts see both studied parts of a smart grid generally as beneficial for our society. However, the state of decentralized electricity storages is regarded to be lagging behind the development of smart meters. On technological as well as on business side further research has to be conducted in order to improve battery efficiencies, decrease costs and

develop appropriate electricity tariffs. Furthermore, this study identified key stakeholders in markets of smart metering as well as decentralized electricity storages. Besides expected players that are already associated with electricity markets, the investigated new components provide enormous opportunities for telecommunication companies having many of the required core competencies as well as further new market entrants.

Moreover, our study revealed manifold costs and benefits for each player. In case of smart metering most benefits have been identified for end-users, electricity retailers and telecommunication companies. For decentralized electricity storages most benefits can be found for distribution system operators and end-users. We determined that in total, benefits outweigh costs. However, private costs outweigh private benefits. Thus, investments are not made, which would be beneficial for society. Hence, a key finding of our analysis is the confirmation of our initial presumption: widely distributed benefits cause situations of positive externalities and thus lead to the omission of a socially desired deployment of examined technologies. We determined factors and reasons for the low diffusion of smart meters as well as decentralized electricity storages. Additionally we identified and discussed measures to foster the diffusion of both smart grid key components.

Our research has important implications for energy market stakeholders and policy makers. First, well-designed and clearly defined regulatory and legal frameworks that are free of contradictions are seen as the most important point by industry experts. To foster investments, legislative authorities have to be aware of the mentioned positive externalities. Ideas to overcome these are either pooling property rights and concentrate distributed benefits on one actor or enabling cooperative business models by implementing appropriate framework conditions. Second, direct regulatory interventions like subsidies or tax releases are currently not seen as the right measure to tackle the slow diffusion. Surprisingly, interviewees supported this viewpoint, although their companies would directly benefit from such interventions. Third, especially in the case of smart meters, standardization and interfaces are

an important issue. To avoid replacements of technical obsolete smart meters in the near future, a modular design is recommendable. This enables future changes and supplements. Fourth, vendors of smart meters have to communicate benefits to end-users in a clearer way. End-users often do not know their possible benefits. Fifth, even though a majority of experts do not see the breakthrough for decentralized electricity storages within the next few years, implementations at specific conditions might make sense already today. Hence, further research could identify possible niches for applications. Sixth, feed-in tariffs for renewables should be designed as power-dependent in order to provide incentives for peak-shaving behavior. Seventh, supportive measures should focus on smart meters in a first step since technology is already further developed than technology of decentralized electricity storages. In the long term, a combination of both: smart metering technology and decentralized electricity storages is reasonable.

7 Limitations and Further Research

This study provides new and valuable insights and knowledge concerning smart metering and decentralized electricity storages. However, there are still some limitations providing avenues for further research.

First, our results are based on the analysis of eight qualitative expert interviews. Even though we reached a level of saturation, findings could be validated by increasing the sample or additionally using the method of expert focus groups. Second, we conducted interviews only with German experts focusing on the German electricity market. Additional, in the case of renewable energies, Germany takes a special role due to the fact that Germany is planning to completely quit nuclear power in the coming years [4]. Therefore, future research should study the diffusion of important smart grid components, not only for one country but on an international level. For example cross-country studies could be conducted and the number of

interviewees can be increased. Third, because of interviewing experts in German, we had to translate the interviews into English. Although we double-checked spelling and translations, this can be seen as a limitation of this study. Fourth, we exclusively used qualitative methods. Future research could combine qualitative and quantitative data to validate our results and quantify positive external effects.

A research gap has been identified for the design of variable tariffs concerning both, smart metering technology and decentralized electricity storages. For example knowledge on end-user reactions on different types of tariffs would provide a helpful basis for the design of reasonable legal and regulatory frameworks. Furthermore, future research can focus on changes in business landscape in the area of smart grids. It seems promising to study opportunities for new collaboration between existing players and how individual players can benefit or lose from that. As this study revealed opportunities for new market entrants, future research could also examine emerging possibilities and study framework conditions in order to identify factors that foster entrepreneurial activities in the area of smart grids.

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