A Perception-based Model for Smart Grid Adoption of Distribution System Operators - An Empirical Analysis

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ABSTRACT

Smart grid technologies (SGT) comprise technologies from various domains, among others information systems (IS). IS can contribute decisively to upgrade the nowadays electromechanically controlled energy systems to electronically controlled networks (Watson, Boudreau and Chen 2010). However, to date the organizational adoption of SGT is rather limited. Thus, we developed a model based upon the technology-organization-environment (TOE) framework (Tornatzky and Fleischer 1990) and validated the model based on data collected from 180 German distribution system operators (DSOs). The model explains .62 of the variance in adoption. Our findings suggest that the technological and regulatory context variables are only minor drivers while the organizational context variables have a substantial impact on the adoption decision. Also the control variables firm size and number of industry clients were found to be significant determinants. The paper's findings will help refining researchers' understanding of organizational technology adoption and will be useful for stakeholders interested in SGT-diffusion.

Keywords

Technology Adoption, Technology-Organization-Environment Framework, Smart Grid, Energy Informatics

INTRODUCTION

The increasing global investments in energy infrastructures are receiving extraordinary attention from policy makers, practitioners, and researchers alike. With the increased feed-in of small decentralized power plants the traditional "top-down" principle of electricity networks is evermore superseded by a "bottom-up" model. This puts a serious strain especially on distribution grids which were solely designed for distribution purposes. Already today the system experiences congestion and atypical power flows while simultaneously the demand for higher reliability and security increases (Massoud Amin and Wollenberg 2005). Also in Europe the energy supply systems' architecture has been developed for large, predominantly carbon-based bulk generation, often located remotely from where the demand occurs (Office for Official Publications of the European Communities 2006). This situation will be additionally exacerbated in the future as on the one hand the diffusion of distributed, often intermittent energy sources is growing and on the other hand it is expected that electricity's share of total energy consumption continues to grow (Massoud Amin and Wollenberg 2005).

Against this backdrop the idea of "smart grids" evolved. This concept involves a multitude of different technologies, referred to as smart grid technologies (SGT) in the following. Information and communication technologies (ICT) are an essential part of these SGTs. Functionally, a smart grid provides new features such as self-healing, increased reliability, demand management systems, or real-time pricing. From a design perspective, a smart grid incorporates technologies such as advanced metering infrastructures, automation and communication technologies, sensor networks, distributed generation, and distributed storage (Brown 2008). All these technologies include IS components which form part of the energy informatics framework proposed by Watson et al. (2010).

While the technologies, features and services discussed are rather similar, the smart grid concept in America and Europe emerged because of different reasons. While the goal in the US is to address the aging infrastructure, improve service levels, and enhance user interaction, the focus in Europe is promoting renewable energy sources (RES) and at least maintaining the level of efficiency, sustainability and reliability (Zhou Xue-song et al. 2010).

No matter where, these challenges predominantly affect distribution system operators (DSO) also referred to as regional transmission operators (RTO or ISO). The DSOs' primary responsibility which is maintaining the stability in the electric grid by balancing generation (supply) with load (demand) across the network is getting evermore complex. As these networks must be operated with a high degree of reliability, resilience, and efficiency the accommodation of RES requires significant changes of the networks' design and operation principle (Hamidi et al. 2010). Although the need for upgrading distribution networks is obvious, one can observe that DSOs are very hesitant to adopt SGTs. The present study thus addresses the question which factors are decisive for DSOs to adopt SGTs.

Hence, this paper aims to contribute to the limited body of knowledge in the area of energy informatics and smart grid adoption. The remainder of the paper is structured in five sections. In the following paragraph, we review prior smart grid definitions, adoption research and elaborate on the TOE-framework, which will be adopted for the purpose of the energy informatics field. In section 3 the research model and hypotheses are presented. We then outline the methodology (section 4) and present the results (section 5). The paper concludes with a discussion of the results and provides implications for research and practice (section 6).

BACKGROUND

Awareness, adoption, and diffusion of the smart grid technologies

To date the smart grid concept lacks a widely agreed definition. Some authors even see the term used as a slogan for marketing purposes (IEC 2012) or merely as an "*umbrella term for a range of technologies which have been developed as an alternative to traditional methods for network operation*" (Hamidi et al. 2010). The International Electrotechnical Commission (IEC) views the smart grid as a concept of modernizing the electric grid by integrating "*electrical and information technologies in between any point of generation and any point of consumption*"(IEC 2012). A comprehensive definition which is more focused on the outcome of the system is used by the National Institute of Standards and Technology (NIST). They consider the term smart grid "*used to describe a modernized grid that enables bidirectional flows of energy and uses two-way communication and control capabilities that will lead to an array of new functionalities and applications*" (NIST 2012). This article follows the definition developed by the European Regulators' Group for Electricity and Gas (ERGEG) stating that "*smart grid is an electricity network that can cost efficiently integrate the behavior and actions of all users connected to it – generators, consumers and those that do both – in order to ensure an economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety*''(ERGEG 2009) as it is function-oriented and does not define any technological trajectories.

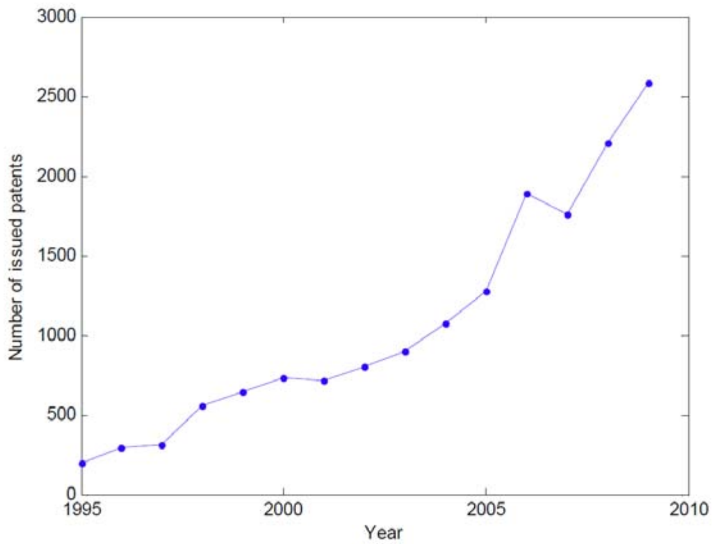

Figure 1. Development of Smart Grid Technology Patents (Ssu-Han Chen et al. 2011)

Smart grid technologies were invented increasingly in the last fifteen years, as shown in figure 1. All technologies which advance the power grid in terms of computation, control and communication are classified as SGTs (Massoud Amin and Wollenberg 2005). Among the most prominent technologies are smart meters, which for different reasons in some countries are used on a large scale like Sweden or Italy and in parts of the United States and Australia (Victoria) (Wolfs and Isalm 2009). In Germany, currently several pilot tests are carried out, but neither the implemented regulatory regime nor the business case behind support the large scale rollout in households.

Prior Research on TOE

In the IS field various models are employed to explain the adoption and diffusion of new technologies and products. While the research engaged in the adoption of technologies by individuals predominantly builds upon the technology acceptance model (TAM) and related models, in the field of organizational adoption several frameworks are used. According to Tan et al. (2007) most studies base on the Diffusion of Innovations Theory (Rogers 1995), the technology-organization-environment Model (Tornatzky and Fleischer 1990), the Institutional Theory (Scott 1987) and the resource-based view (Wernerfelt 1984). Recently approaches to mingle these theories were examined. Zhu and Kraemer (2005) for instance combined the TOE framwork and the resource-based theory. We chose the TOE framework as it has proved to be a useful framework for studying the organizational adoption of especially IS-centric technologies (Kuan and and Chau 2001, Mishra, Konana and Barua 2007, Zhu and Kreamer 2005, Zhu, Kraemer and Xu 2003, Zhu, Kraemer and Xu 2003). The framework was developed as a generic theory to study the adoption of general technological innovations. Tornatzky and Fleischer (1990) identified the technological context, the organizational context and the environmental context as the three aspects of an organizations' context that influence the process by which technological innovations are adopted. The authors see their framework as a model which can be regarded as an "*attempt to capture the panorama of technological innovation, including people, organizations, and politics, and their relationships to one another*"(Tornatzky and Fleischer 1990). The authors intent is "*to portray not only what happens during the innovation process, but why it happens*" (Tornatzky and Fleischer 1990). The framework is consistent with the theory of innovation diffusion (Rogers 1995) and his theoretical analysis of technological characteristics and the internal and external characteristics of the organization. Several empirical studies in various IS domains were already conducted to examine the validity of the framework (Zhu et al. 2003, Zhu and Kraemer 2005, Zhu et al. 2006) In particular, Kuan and Chau (2001) developed a perception based TOE framework including six factors (direct benefits, indirect benefits, cost, technical competence, industry pressure, and government pressure) to predict the adoption of Electronic Data Interchange (EDI). Their empirical study confirmed the validity of the TOE framework for the adoption of technological innovations (Kuan and Chau 2001). Consistent with the argumentation of Kuan and Chau (2001) our instrument builds upon so called "secondary" characteristics of innovation, which can be measured subjectively from the viewpoint of the perceiver. The "primary" characteristics are inherent to the innovation and can be measured objectively, but sometimes fail to consider the different subjective behaviors and perceptions of the adopter. That is different adopters might perceive primary characteristics in different ways which will eventually lead to that their behaviors will differ.

RESEARCH MODEL AND HYPOTHESES DEVELOPMENT

Using the TOE framework we developed a perception-based model for the adoption of SGT as illustrated in Figure 1. Based on the literature we identified seven determinants of SGT-adoption. We elaborate on each of the seven factors in the following.

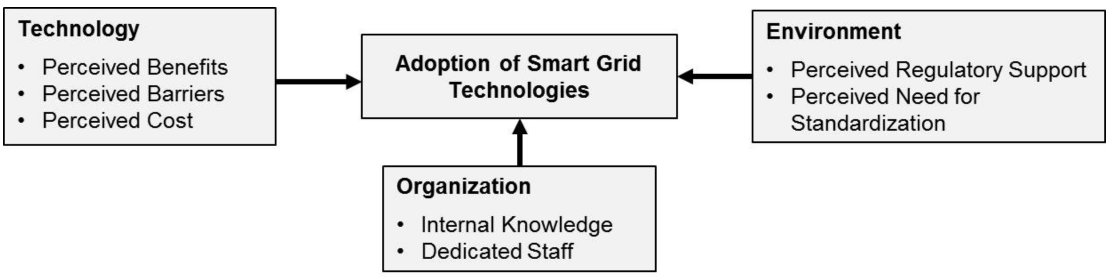

Figure 2. The Research Model

Technological Context

Availability of technology can be regarded as a necessary condition for a successful implementation. The performance characteristics and the maturity of the technology determine the associated risks of adoption. The different categories of innovation exhibit that efficient process innovations can take place only through major changes (Tornatzky and Fleischer 1990). A comprehensive introduction includes a significant breaking away from the previously employed technologies and the associated equipment. Both Hirschorn (1988) and Tornatzky and DePietro (1987) emphasize that the introduction of complex technologies needs not only advanced technical knowledge for the implementation but also sophisticated knowledge in the organization to make use of the benefits and to avoid the traps of the new technology. New technologies have also mostly still no final maturity when first implemented and are subject to ongoing developments. Tushman and Nadler (1986) explain that radical innovations as compared to incremental innovation are often afflicted with significantly greater uncertainty about the impact of the implementation. The entrepreneurial risk associated with adoption grows also with increasing uncertainties. Adopters may only take the risk if compelling features are available and expectable to a certain degree. Therefore, we propose:

Hypothesis 1: Perceived benefits positively influence the adoption of smart grid technologies.

Hypothesis 2: Perceived barriers negatively influence the adoption of smart grid technologies.

Hypothesis 3: Perceived costs negatively influence the adoption of smart grid technologies.

Organizational Context

Owing to the multitude of different technologies involved and the energy system's complexity adopting SGTs require a substantial degree of technical competence. As installing a single technology has numerous interactions and consequences for the whole energy system's functioning, the risks associated with adopting SGTs for DSOs is particularly high. Electricity grids are fragile in terms of a single point of failure can have serious consequences for the whole system. Research in organizational science emphasizes the effect of internal know-how and organizational learning on innovation adoption. Attewell (1992) states in this respect that "*firms delay in-house adoption of complex technology until they obtain sufficient technical know-how to implement and operate it successfully.*" Adopting complex technologies can therefore be seen more like a process of knowledge accumulation rather than a single event (Chau and Tam 1997). Innovations which adoption resembles a "learning by doing" process that can be attributed to certain characteristics (Attewell 1992) that mostly apply to SGTs. (1) SGTs have an abstract and demanding scientific base. Smart grids aim at interconnecting and controlling a large number of different devices like decentralized power plants and energy-consuming appliances. The sheer number of components makes this a demanding task, but beyond that, the level of complexity increases exponentially when considering the different versions of these components. Given the complexity there is high likelihood that the whole energy system's behavior cannot be determined accurately. (2) SGTs are no ready-made solution. Each and every DSO has to individually analyze and customize the technologies' characteristics dependent on the condition of the distribution grid and the IT infrastructure. As the technologies cannot be mass produced each implementation is unique and cannot be experienced in its entireness. (3) SGTs cannot be treated as "black boxes". DSOs need an understanding of the mode of operation to assess the interactions with other system's components. Thus DSOs are required to have a broad tacit knowledge base and procedural expertise to use SGTs effectively. Moreover, their knowledge base needs to be updated frequently as the smart grid sector is characterized by rapid market dynamics and fast changing regulatory requirements. In light of the rapid and global growth of knowledge the creation and acquisition of those knowledge assets is difficult (Arora and Gambardella, 1994). Thus, knowledge acquisition requires both integrating internal and external knowledge sources (Porter and Stern 2001). Although, evermore external knowledge is available for firms they cannot simply rely on outside knowledge inflows (Escribano, Fosfuri and Tribo 2009) because for the recognition and assessment of the value of new information and, more generally, the learning of new knowledge prior internal knowledge is required. Hence, a certain level of internal knowledge is regarded as a prerequisite for what is called absorptive capacity (Cohen and Levinthal 1989, 1990). Hence, many firms have established departments that are devoted to acquire and distribute knowledge from inside and outside the organization to develop organizational capabilities of creating, acquiring and (re-)combining knowledge assets. Based on these above viewpoints, the following hypotheses are proposed:

Hypothesis 4: Internal knowledge positively influences the adoption of smart grid technologies.

Hypothesis 5: The existence of dedicated staff positively influences the adoption of smart grid technologies.

Environmental Context

In most electricity markets distribution networks are treated as natural monopolies. Sunk costs and economies of scale in electricity delivery make duplicating such networks unfeasible (Viscusi, Harrington and Vernon 2005, Joskow 2005, Picot 2009). In order to avoid monopolistic exploitation of these natural monopolies, third party network access and revenues for network usage are regulated mostly under a price-cap or incentive regulatory regime (Wilson 2002, Woo, Lloyd and Tishler 2003, Glachant and Finon 2003, Shioshani and Paffenberger 2006). Within these regimes DSOs' revenues are regulated by national regulatory authorities (NRA). Mostly DSOs are remunerated based on the amount of electricity delivered hence they have an incentive to transport as much electric power as possible to consumers. Although NRAs are increasingly aware of this problem and switched to RPI-X-regulation (retail price index minus expected efficiency savings), DSOs still have an (though reduced) incentive to increase, or at least stabilize, the amount of electricity delivered (Diekmann et al. 2006). Hence there is a discrepancy between DSOs regulatory incentives and investments in SGT. Simultaneously the increasing feed-in of intermittent - often distributed - RESs puts a serious strain on distribution grids. Without fundamentally modernizing the distribution grids' infrastructure, RESs' increasing penetration will result in a decline of the grid's reliability, resilience, efficiency, and environmental sustainability. Thus, in order to stimulate the adoption of SGT and the efficient incorporation of RES, DSOs' adoption decisions will depend on the incentives given by NRA. Hence, we contend that:

Hypothesis 6: Perceived regulatory support positively impacts the adoption of smart grid technologies.

Most cumulative technologies like smart grids are in the nature of system products, that is, "*products that permit or require the simultaneous functioning of a number of complementary components*" (Langlois 2001) . Competition of system products can be distinguished in inter- or intra-system competition. While inter-system competition is in many ways more common, in the case of smart grids the competition occurs at the level of components within the energy system. This form of competition requires at least some degree of openness and modularity. Although, industry, academia, governmental organizations, and associations are globally engaging in identifying or developing open and non-proprietary standards and protocols (NIST 2009, NIST 2010, DKE 2010, ENSG 14, METI 2010), utilities and other stakeholders are still blaming NRAs for indefinite and fuzzy requirement specifications. A well-known example for the positive effect of open and non-proprietary standards in a market with intra-systems competition is the GSM standard which spurred investments in mobile networks and the diffusion of mobile telephony. Analogous, DSOs will be more inclined to adopt SGTs when the perceived level of standardization is high and the perceived risks of technological obsolescence and non-interoperability are low. Thus, we state:

Hypothesis 7: Perceived need for standardization negatively impacts the adoption of smart grid technologies.

RESEARCH METHODOLOGY

Sample and data-collection procedure

To validate the research model we collected data from May to June 2011 via a postal survey addressing C-level managers of the 861 German DSOs. A pretest of the initial survey instrument was conducted with two energy-technology experts in executing positions at energy utilities. We conducted face-to-face interviews with the pre-testers to ensure that all questions are consistent, easy to understand and the questions' sequence is appropriate. Due to the feedback the model was modified and some items were revised. Within six weeks 184 companies responded from which four had to be eliminated due to missing values so that finally our sample consists of 180 network operators (response rate: 20.9%).

Measures

Using scale items that are derived from previously suggested and validated measures was not possible as the adoption of SGT is very different from the adoption of other IT artifacts. Therefore, the majority of items was specifically developed for this study based on the literature of various sources including trade journals and pamphlets published by SGT-vendors and governmental organizations. We operationalized the factors as follows.
If not indicated otherwise all items were rated on six-point Likert scales with the anchors "strongly disagree" (1) and "strongly agree" (6). Perceived benefits were measured by asking respondents to assess SGTs' potential (1) to facilitate new services and (2) to increase the profitability of the network infrastructure. The construct showed good internal consistency (Cronbach's $\alpha = .79$). Perceived barriers were operationalized with four items. Respondents were asked to indicate whether they fear that smart grids bring about (1) more demanding customers, (2) higher costs for maintaining the networks grids' reliability, (3) more competition, and (4) lower margins. The variable showed sufficient internal consistency (Cronbach's $\alpha = .71$). Perceived cost was operationalized using one item asking respondents if the investment costs are too high. Internal knowledge and dedicated staff were also operationalized by employing a single-item measurement as for concrete singular objects single-item measures should be used (Bergkvist, 2007). Respondents were asked to assess whether the internal knowledge base was sufficient. The existence of dedicated staff was determined by a binary measure: firms with dedicated staff and firms without dedicated staff. Perceived regulatory support was measured employing two items asking respondents to indicate if the regulatory provisions are (1) sufficiently specific and (2) provide adequate incentives to invest in SGT. The construct showed very good internal consistency (Cronbach's $\alpha = .84$). Perceived need for standardization included to items asking respondents if the regulator should specify (1) standards for SGT and (2) how to exchange data between the energy systems' actors. The variable showed sufficient internal consistency (Cronbach's $\alpha = .72$). The dependent variable, smart grid

technology adoption was determined by asking respondents how much they have already invested in SGT (coded as 1 = 0-100.000 €, 2 = 100.000-300.000 €, 3 = 300.001-600.000 €, 4 = 600.001-1.000.000 €, 5 > 1.000.000 €).
Prior to entering in the analyses some reverse coded items were recoded. Additionally data for the control variables firm size (coded as 1 =< 100 Mio. €, 2 = 100-250 Mio. €, 3 = 251-500 Mio. €, 4 = 500-750 Mio. €, 5 > 750 Mio. €) and number of industry clients (coded as 1 =< 50, 2 = 50-200, 3 = 201-500, 4 > 500) was obtained from the survey.

RESULTS

To test the model a regression analysis was conducted. This approach is commonly used when both independent and dependent variables are ordinal or metric (Oh, Ahn and Kim 2003). Further, regression analysis was chosen because of its comprehensibility (Goodhue, Lewis and Thompson 2007). IBM SPSS Statistics version 19 was used to analyze the data. Table 2 provides the descriptive statistics and correlation coefficients.

		Mean	STD	1	2	3	4	5	6	7	8	9	10
1	SGT Adoption	1.55	1.11	-									
2	Perceived Benefits	3.04	1.36	.19*	-								
3	Perceived Barriers	3.67	1.23	-.15*	.23**	-							
4	Perceived Cost	5.14	1.13	-.11	-.20**	.12	-						
5	Perceived regulatory support	2.18	1.49	-.22**	.00	.07	-.03	-					
6	Need for Standardization	3.76	1.61	.01	.15	.18*	.05	-.13	-				
7	Internal Knowledge	3.85	1.22	.38**	.22**	-.15*	.10	-.01	.09	-			
8	Dedicated Staff	1.16	.37	.51**	.27**	-.05	-.20*	-.05	-.06	.34**	-		
9	Firm Size	2.81	1.49	.49**	.18*	-.08	.06	-.19*	-.06	.35**	.33**	-	
10	No. industry clients	1.64	1.07	.71**	.15	-.07	.01	-.26**	.06	.34**	.52**	.54**	-

Note. N = 180. * p < .05. ** p < .01.

Table 2. Mean, standard deviations and correlations for study variables

Table 2 shows that some of the variables of interest are correlated. Hence, in order to assess construct validity, a confirmatory factor analysis was conducted employing principal component analysis with varimax rotation and Kaiser normalization. All items loaded appropriately and above the threshold of .40 (Straub, Boudreau, & Gefen, 2004). Moreover, the eigenvalues of all constructs were greater than 1.0. Thus, the results of the factor analysis fulfill the criteria for both convergent and discriminant validity (Straub et al. 2004). We also tested for multicollinearity as presented in table 3. The results give no indication for multicollinearity contaminating the results (Neter, Kutner, Wasserman and Nachtsheim 1996). Further, the means of the variance inflation factors (VIF) were not significantly greater than 1 in any of the models. Table 3 also shows that the tolerance values do not point to multicollinearity being an issue (Brace, Kemp and Snelgar 1996). To rule out common methods bias we also performed Harman's single-factor test (Podsakoff, MacKenzie, Lee and Podsakoff 2003). Common methods bias may occur as both independent and dependent variables were measured using the same instrument. In Harman’s single-factor test, an unrotated exploratory factor analysis including all items is conducted to check whether a single factor emerges or one factor accounts for a large portion of the variance. In our test, 16 factors emerged. The largest factor accounted for .21 per cent of the variance. Both results indicate that common methods bias is not a concern. The results of the regression analyses are depicted in table 3.

Variable							
Dependent	**Independent**	**β**	**t**		**R^2_{adj}**	**Tolerance**	**VIF**
SGT Adoption	Perceived Benefits	-.05	-.90		.62	.77	1.29
	Perceived Barriers	-.03	-.48			.80	1.25
	Perceived Cost	-.16	-2.84	***		.82	1.21
	Perceived regulatory support	-.10	-1.68	*		.85	1.17
	Need for Standardization	-.11	-1.86	*		.87	1.15
	Internal Knowledge	.14	2.23	**		.64	1.56
	Dedicated Staff	.20	2.91	***		.64	1.57
	Firm Size	.14	2.10	**		.64	1.57
	No. industry clients	.47	6.45	***		.54	1.85

Note. N = 180. * p < .10, ** p < .05, *** p < .01.

Table 3. Multiple regression results

Regarding the technological context variables the results indicate that only perceived costs (β = -.16, $p < .01$) have a significant influence on SGT adoption while the hypotheses concerning perceived benefits and barriers were not supported by the data. Both environmental context variables perceived regulatory support (β = -.10, $p < .10$) and perceived need for standardization (β = -.11, $p < .10$) were found to be significant at the .10%-level. Concerning the organizational context both constructs internal knowledge (β = .14, $p < .05$) and dedicated staff (β = .20, $p < .01$) proved to confirm the predicted positive relationships. Further, both control variables firm size (β = .14, $p < .05$) and number of industry clients (β = .47, $p < .01$) were found to have a significant impact on SGT adoption. In total the dependent and control variables accounted for a substantial amount of variance in SGT adoption (R^2adj = .62).

DISCUSSION AND CONCLUSION

The future vision of a sustainable and low-carbon economy can only be achieved when SGTs enable the effective and efficient integration of distributed – often intermittent – RESs. As many of these RESs feed-into the distribution grid, the modernization of these grids is essential. Nevertheless, one can observe that many DSOs adopt a "wait and see" policy instead of being early adopters of SGTs. Our study therefore aimed to analyze which technological, organizational and environmental factors determine the SGT agenda of DSOs based on a TOE-framework. Thereby our paper contributes to research in organizational technology adoption and to research in energy informatics.

An intriguing finding is that technological characteristics seem to have at best a moderate impact on DSOs' decisions to adopt SGTs. In fact only perceived cost was found to (negatively) influence SGT-adoption while perceived benefits and barriers did not affect adoption. These findings support the notion that most DSOs regard SGTs – at least to date – more than a cost factor rather than an efficiency-enhancing and distinguishing feature (Kurtz, Netzband, Albert, & Hahn, 2008). Both environmental variables were found to have a moderate impact on SGT adoption. While the negative influence of perceived need for standardization was expected, the negative influence of perceived regulatory support was somewhat puzzling. One can only speculate why more regulatory support is associated with lower investments in SGT. A potential interpretation may be that DSOs perceive regulators' support regarding the deployment of smart grids as a factor that limits their own entrepreneurial freedom of choice. Our study found that the organizational context variables have the greatest influence on the adoption of SGTs. In line with findings in organizational learning and corporate research and development (R&D) the availability and diversity of internal knowledge and the existence of knowledgeable personnel have a positive impact on SGT-adoption (Cohen & Levinthal, 1990; Nonaka, 1994). In an area in which radical technological innovations have rarely occurred and the typical life cycle of technologies and amortization period of investments is rather decades than years, the accumulation of internal and external knowledge seems particularly important. Moreover, the deployment of SGTs is not a mass customizable process. Rather it requires energy utilities to experiment with new technologies and thus to develop "exploration capabilities". A capability which these firms were not required developing in the past. However, as massive changes in energy supply systems are foreseeable energy utilities are forced to "say goodbye" to the traditionally very stable environment and to develop dynamic capabilities for which the accumulation of internal and external knowledge is a prerequisite (Teece, Pisano, & Shuen, 1997). After downsizing and deregulation many utilities do not have the necessary R&D resources (Hamidi et al. 2010) so that they will have to learn how to manage themselves in an environment in which the rate of innovation will become higher, competition is more intense and services will become more important (Arora, Fosfuri, & Gambardella, 2001).

The control variables firm size and especially the number of industry clients were found to have a great influence on the adoption of SGTs. As smaller firms face severe constraints regarding human and financial resources they often lag behind large firms in the use of technology. Moreover they often have limited knowledge and education as recruiting and retaining internal experts is difficult as career opportunities in small businesses are restricted. A very intriguing result of our study is that the number of industry clients is the most important factor for SGT adoption. Industry clients such as manufacturing firms often have energy-intensive business processes which can underlie large variations. These variations pose serious challenges for distribution networks as they cause instability in their distribution area and make planning and maintaining networks a difficult task. Thus, this finding suggests that the higher the number of industry clients in a distribution area the more DSOs' perceive SGTs as useful means to cope with the above mentioned challenges.

As with any other empirical study, this paper has limitations that should be considered when interpreting the results. As our study investigated only one country, namely Germany, future research may investigate the adoption of SGT in other countries to account for different regulatory regimes and to improve the generalizability of the findings. Furthermore, we employed a correlational design, which limits our ability to draw causal inferences. Future research may use other causal designs. We also encourage future research in organizational technology adoption to delve more deeply into the effects of the internal knowledge base as our findings suggest that they are more important than technological and environmental factors. Our study's results suggest that in the light of a regulated market, technology adoption of organizations is very different from unregulated ones as technological and environmental factors only had a moderate influence on adoption. Therefore, more research is needed to extend our understanding of technology adoption decisions of organizations active in regulated markets.

For policy makers and practitioners our findings make clear that the there is an urgent need for refining regulatory regimes and further developing standards in smart grids. As competition in smart grids occurs at an intra-system level some degree of interoperability is needed that the multitude of different modular components can work together seamlessly. In order to encourage more R&D and risk taking with innovative smart grid technologies, NRAs should further consider to follow the British regulators OFGEM's example and create an "Innovation Funding Incentive" that allows DSOs to spend a certain percentage of their regulated return on R&D projects, of which 80% can be passed on to consumers (Bauknecht, Leprich, Späth, Skytte, & Esnault, 2007; OFGEM, 2009). Our findings confirm the need for changes in the regulatory system as DSOs, which are the most affected parties in energy supply systems' transition, lack appropriate economic incentives to promote upgrading to smart grids.

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