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Power Control to the People? Private Consumers' Acceptance of Smart Meters

LMU Munich Kranz
LMU Munich, kranz@lmu.de

Julia Gallenkamp
LMU Munich, gallenkamp@lmu.de

Arnold Picot
LMU Munich, picot@lmu.de

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POWER CONTROL TO THE PEOPLE? PRIVATE CONSUMERS' ACCEPTANCE OF SMART METERS

Kranz, Johann, Ludwig-Maximilians-University Munich, Ludwigstr, 28, 80539 Munich, Germany, kranz@lmu.de

Gallenkamp, Julia, Ludwig-Maximilians-University Munich, Ludwigstr, 28, 80539 Munich, Germany, gallenkamp@lmu.de

Picot, Arnold, Ludwig-Maximilians-University Munich, Ludwigstr, 28, 80539 Munich, Germany, picot@lmu.de

Abstract

The increasing diffusion of renewable energies which underlie significant daily and seasonal fluctuations increases grid operations' complexity. For the effective use of renewable energies, innovative information and communication technologies (ICT) and concepts are necessary to efficiently balance power generation and consumption. An ICT-based innovation in this context is the smart metering technology. High-end smart meters, like advanced meter management (AMM) solutions, comprise a broad range of new services which are vital to an ICT-based energy system (e-energy) by enabling the bidirectional transfer of timely and reliable information between components of an energy system. However, to date the acceptance of smart meters has not been investigated. Using a context-specific extension of the Technology Acceptance Model (TAM) of Davis (1989), our study investigates smart meters' acceptance based on the attitude toward use and the salient beliefs perceived usefulness, perceived ease of use, and subjective control. Results support the theorized relationships indicating that the attitude toward use fully mediates the relationship between perceived usefulness, perceived ease of use, and subjective control on intention to use. In the conclusion a detailed discussion of the study's findings is provided and the implications for research, practice, and policy are highlighted.

Keywords: Technology Acceptance, Smart Meter, Smart Grid, Green-IT

1 INTRODUCTION

In recent years the European energy market has undergone major transitions. Forced by the institutions of the European Union the market was largely liberalized and hitherto vertically integrated firm structures were unbundled by separating production from distribution. However, as the network functions represent natural monopolies, competition was particularly promoted in the areas of production and supply. Simultaneously, due to the climate change, an increasing energy demand, scarce fossil resources, and rapid technological advancements in power engineering issues of future energy supply and efficient energy usage are attracting ever more attention from researchers, practitioners, and public policy. Globally, many initiatives are launched which aim at enhancing energy efficiency, securing supply, and mitigating climate change. An integral part of these efforts is the promotion of renewable energies. Considering that in Germany the ratio of fluctuating (e.g., solar, wind) to adjustable (e.g., nuclear, coal, or gas) power generation is assumed to change from 1 : 6 today to 1 : 1.3 in 2030, the requirements for the energy system and, especially, the grid infrastructure will increase drastically. At each point in time grids have to be able to satisfy demand and react to unforeseen peaks. Hence, increasing the share of power generated by fluctuating energy sources makes grid management by far more complex.

Consequently, as mobile or fixed broadband connections are available in most regions and the performance and integration ability of modern ICT is substantial, the intention is to create an ICT-based network comprising the entire energy system from power generation to consumption. By facilitating components of an energy system to exchange information, grid management can operate more anticipatory and, thereby, enable the reduction of carbon emissions as energy is used more efficiently. The convergence between ICT and the energy system is referred to as e-energy ("internet of energy"). The term e-energy comprises a broad range of ICT-based innovative concepts whose goal is to facilitate the intelligent management and control of the entire energy system across all value-added steps. In an ICT-based energy system smart meters are an integral technology enabling bidirectional data exchange (e.g., with power providers, grid management), time- and load-based consumption measurement, and the provision of information to consumers concerning their current usage. A study conducted by the German Federal Ministry of Economics and Technology (FMET) indicates that simply by providing this information energy consumption can be decreased significantly (FMET 2006). To date (basic) smart meters have been launched on a large scale only in few countries (e.g., UK, Italy, Sweden). Although the positive impact of smart meters on energy efficiency is widely recognized (FMET 2006), the diffusion of the technology is still retarded. Among others, an important reason for the slow diffusion lies within the unexamined acceptance of the smart metering technology by private consumers. Thus, the intention of our study is to close this gap by scrutinizing private users' acceptance of the smart metering technology.

For this purpose data from a sample of 212 consumers was collected to test theorized relationships that draw upon an extended version of Davis et al.'s (1989) TAM. The TAM is a widely recognized model that has attracted considerable attraction in IS and IT research and practice (Lee et al. 2003, Venkatesh et al. 2003). The model has been shown to have good predictive power (Davis 1989, Davis et al. 1989, Mathieson 1991, Davis 1993), and constructs of high validity and reliability (Davis 1989, Adams et al. 1992, Hendrickson et al. 1993, Subramanian 1994, Chin et al. 1995, Doll et al. 1998, Agarwal et al. 1999, Yang et al. 2004). Hence, the TAM is applied to explain and predict technology acceptance in a broad variety of IT contexts (Mathieson 1991, Adams et al. 1992, Segars et al. 1993, Chin et al. 1995, Doll et al. 1998). In the literature several revisited and extended versions of the original TAM have been proposed (for an outstanding review, see Venkatesh et al. (2003)). For our study we choose the initial TAM as theoretical foundation, because of its ample acceptance, generalizability, and explanatory record (Venkatesh et al. 2003). The TAM is based on the assumption that perceived ease of use and perceived usefulness are salient beliefs which affect an individual's attitude toward the usage of a technology. Attitude in turn is hypothesized to determine behavioral intention to use and eventually the actual usage. For the purpose of our study we extend the TAM by adding the construct of subjective control, originating in the field of social psychology. As we examine the acceptance of smart meters in private settings, we suggest that control has an important influence on the acceptance of smart meters.

2 CONCEPTUAL BACKGROUND

2.1 The role of smart meters in e-energy

Power is grid-bound and possibilities to store power are strongly restricted, beyond being inefficient and costly. Consequently, at each point in time an energy system has to be able to react to variations in the demand of households and industry to ensure security of supply. To date power supply and demand is coordinated on the basis of standardized load profiles. However, when unpredicted peaks in demand occur, natural gas peaking power plants have to be fired-up. These plants are not only costly to operate but also cause higher pollution. Considering, the global political intent to increase the share of power generated by fluctuating energy sources the need for an intelligent coordination additionally increases. The situation is further exacerbated by the fact that hitherto energy systems' components and actors are interconnected to a very limited extent which hampers the intelligent and anticipatory coordination of power generation and consumption. In this context, e-energy comes to the fore. E-energy can be referred to as a holistic approach that aims to facilitate the intelligent management of the entire energy system across all value-added steps from production to consumption based upon ICT.

An e-energy system consists of various technologies and concepts which are outlined shortly in the following.

- As all entities of an e-energy system are connected with each other, an intelligent grid infrastructure is needed, commonly referred to as a smart grid. Besides the transportation of power, smart grids enable bidirectional processing of information. Hence, smart grids are an important technology to ensure complex grid operations and can be regarded as the "central nervous systems" of future energy systems.
- Vehicle to Grid (V2G) is a concept in which electric and hybrid cars are used to either store or release power dependent on the current grid load situation.
- The concept of virtual power plants accounts for the varying availability of renewable energy sources by clustering, connecting, and controlling a large number of small and medium sized power plants such as biomass, wind, solar, fuel cell, and combined heat and power plants as well as storage elements like pumped storage hydro power stations. The idea is to increase stability and reliability of supply by clustering numerous decentralized power plants (Kueck 2009).
- Augmenting demand elasticity and influencing load curves in a beneficial way, i.e. smooth peaks in demand, is the goal of various Demand Response (DR) programs that are summarized under the term Demand Side Management (DSM). Hence, DSM helps to mitigate the strain of power grids and to ensure grid reliability.
- Internet-based energy marketplaces facilitate an easy market access for customers who also operate small power plants ("prosumers") allowing the trade of power between various actors of market participants to permanently equalize power supply and demand.

Since the outlined approaches all depend on reliable and timely information about consumption the essential role of smart meters becomes obvious (Kueck 2009). To establish a shared conceptualization for our study we refer to an (electronic) meter as a smart meter only when it is combined with an advanced metering management (AMM) system (DRSG 2009). The AMM system provides the literal "intelligence" by collecting usage data from the electronical meters and providing this information to consumers (e.g., via internet portals), utilities, grid operators, or other parties. Additionally, these systems facilitate the practical execution of demand response programs as well as other features relating to customer service (e.g., remotely (dis-)connecting the power connection), value-added services (e.g., security or assistance services, home automation), or system operation (e.g., manipulation detection, outage management) (Wissner 2009). Thus, smart meters are essential components of the future energy system (see Figure 1) characterized by an increasing process complexity due to liberalized market structures and efforts to decrease carbon emissions.

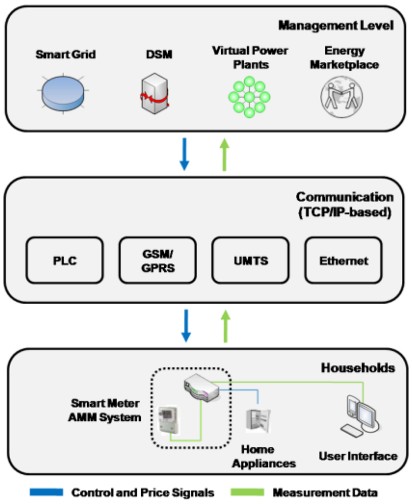

Figure 1. Potential information flows in an e-energy

The focus of this study is on power metering, however, advanced smart meters are not limited to electrical power. They can also be employed for metering other kinds of energy (e.g., water, gas, heat). With the usage of smart meters in private settings, issues of privacy and self-determination arise. Consumers may have concerns to reveal information about their private life and habits plus additionally give up some control over their home appliances regarding automated interventions by others. Thus, to clarify the question of private consumers' acceptance of smart meters is the intention of our study.

2.2 Research Model and Hypotheses

The TAM as proposed by Davis (1989) draws upon the theory of reasoned action (TRA) (Ajzen et al. 1980). Its specific intention is to explain and predict information technology's acceptance and usage in the workplace based on variables such as beliefs, attitudes, and behavioral intention (Davis 1989, Davis et al. 1989). The model contends that the salient beliefs perceived usefulness and perceived ease of use determine an individual's attitude toward usage. Perceived usefulness is defined as the "*prospective user's subjective probability that using a specific application system will increase his or her job performance*" (Davis et al. 1989). For the context of our study, usefulness is related to energy efficiency, potential cost savings, and real-time information about power consumption in private settings. Perceived ease of use "*refers to the degree to which the prospective user expects the system to be free of effort*" (Davis et al. 1989) respective to mental and physical efforts as well as ease of learning (Yang et al. 2004). Further, the TAM assumes that behavioral intention is determined by perceived usefulness together with attitude. Intention in turn is assumed to affect actual usage. Finding that attitude is of weak explanatory power, Davis et al. (1989) and Venkatesh and Davis (2000) exclude this construct from the revisited version of the TAM. Nevertheless, there are many recent studies that build upon the initial model (e.g., Mathieson 1991, Venkatesh et al. 1996, Karahanna et al. 1999, Riemenschneider et al. 2001), as the revisited TAM is likely to restrict comprehensive understanding of technology acceptance and its adaptation is simply based on empirical results, rather than theoretical considerations (Kim et al. 2009). The TAM has been used to study the acceptance of a broad variety of technologies like e-mail (Straub 1994, Karahanna 2000), e-commerce (Bhattacherjee 2001), telemedicine technology (Hu et al. 1999), computers (Igbaria et al. 1995, Agarwal et al. 1999), mobile telecommunication innovations (Wang 2008), smart card-based payment systems (Plouffe et al. 2001), ubiquitous computing applications (Beier et al. 2006), or mobile data services (Hong et al. 2006). Hence, although originally proposed for IS and IT, the TAM has also proved to be a useful model for explaining and predicting the acceptance of other technologies (Wang 2008). Thus, in our study we employ the initial TAM, however, with some modifications due to the specific setting.

First, the model's dependent variable is behavioral intention to use as no data for actual usage could be obtained. This adaption is commonly made (Hu et al. 1999, Lai et al. 2005, Phang et al. 2005) and is unlikely to cause bias as both, theory and empirical results, suggest a strong correlation between intention to use and actual usage (Vijayasarathy 2004).

Second, the hypothesized positive relation in the TAM between perceived usefulness and behavioral intention to use violates the assumption of the TRA (Taylor et al. 1995), as the TRA argues that attitude is responsible for full mediation. The notion of Davis et al. (1989) was that in the workplace the intention to use a system is only in parts based on an individual's attitude, but is rather a matter of expected job performance. In other words, an individual may use a system because of its positive impact on job performance, although disliking it (Davis et al. 1989). However, investigating technology acceptance of consumers in a private setting differs from workplace settings as usage is not mandatory and additionally no training and support is provided. Hence, we eliminated this relationship from our model, assuming that intention to use is based on an individual's attitude toward usage.

Third, even though in the area of IS research attitude has been treated as an ambiguous and inconclusive construct (Legris et al. 2003), in psychology its relevance for individual behavior has always been emphasized (Yang et al. 2004, Kim et al. 2009). However, Davis et al. (1989) omitted attitude from the revised TAM arguing that its influence on intention to use or actual usage is limited and at best a partial mediator. But, as shown by a meta-analysis of empirical studies using TAM the mediating effect of attitude varies considerably between studies (Kim et al. 2009). Analyzing the experience respondents had with the technology in question, Kim et al. (2009) found that the mediating role of attitude is contingent on a sample's prior experience with a technology. The more experienced the participants were the higher was the mediating effect of attitude. Participants in our study did not have experiences with smart meters. However, through a comprehensive multimedia presentation of a smart meter's primary functions and usage scenarios within the online survey, respondents were enabled to better assess and anticipate "hands-on" usage. Further, within the survey the assumption was made that information about usage (e.g., current power consumption and price, analysis of consumption) is presented to users via a web-based user interface. Therefore, an important part of the user's interaction with smart meters occurs in a technological environment, namely the internet, in which the participants had at least some experience since the survey was conducted online. Psychology further suggests that attitude guides an individual's behavior by filtering information and shaping an individual's perception of the world (Fazio 1986). It reflects a person's evaluation of performing a certain behavior, i.e. adopting a technology, is good or bad. Related to technology acceptance, attitude delineates the extent to which a person dislikes or likes to use a technology (Venkatesh 1999). In sum, we hypothesize attitude to mediate the relationship between salient beliefs and intention to use.

Fourth, we extend the TAM by adding the construct of subjective control. The variable subjective control can be viewed as a control record (Beier et al. 2006). A person's need for control is related to her or his perceived ability to control a technology. In case that the experienced control falls below this need, a subjective loss of control is the consequence which leads to negative emotions (Beier 2004). These emotions are hypothesized to affect a person's attitude to use a technology (Beier et al. 2006). With subjective control the model takes into account that beyond rational factors also emotions affect the acceptance of the smart metering technology as it permeates everyday private life by, e.g. gathering and transferring highly confidential private data to other parties or automatically switching off home appliances. This influence of psychographic factors on individual's behavior is widely recognized in IS, psychology, and consumer behavior literature (Rokeach 1973, Davis et al. 1992, Agarwal et al. 1999, Featherman et al. 2003, Schiffman et al. 2004). Studying the acceptance of ubiquitous computing applications the significant influence of subjective control on acceptance was shown (Beier et al. 2006). Thus, we contend that consumers' acceptance of smart meters is dependent on beliefs if and to what extent the metering technology can be controlled. According to our statements and the relationships proposed in the initial TAM, the hypotheses can be stated as:

Hypothesis 1: Perceived ease of use positively influences perceived usefulness of smart meters.

Hypothesis 2: Attitude toward use mediates the relationship between perceived usability and intention to use a smart meter.

Hypothesis 3: Attitude toward use mediates the relationship between perceived ease of use and intention to use a smart meter.

Hypothesis 4: Attitude toward use mediates the relationship between subjective control and intention to use a smart meter.

Hypothesis 5: Attitude toward use of smart meter has a positive effect on intention to use.

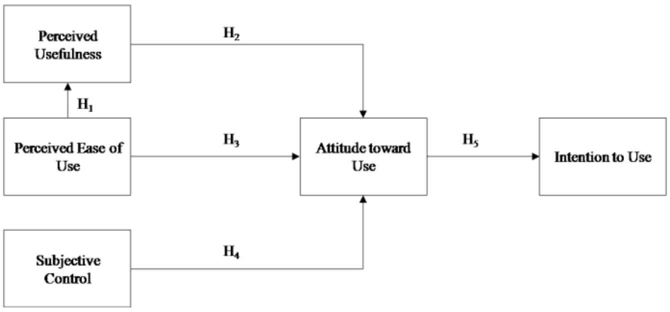

Figure 2. The research model.

3 METHOD

3.1 Sample and Procedure

We obtained the data from an online survey. The survey was run in March 2009 for 14 days after a pretest in February 2009. Besides being sent to participants, the link to the survey was, among others, posted on the official e-energy project website of the FMET. This study set out to investigate the evaluation of smart meters by potential customers. Since the technology is relatively new to customers, participants may have little information regarding this technology. In order to eliminate this potential interfering variable the study integrated multimedia illustration (videos, pictures, textual description) of smart meters and user interfaces that display diverse information about energy consumption. An initial sample of 351 participants took part in the study, 60% completed the survey. Participants' age ranged from 18 to 78 (18-19 years (1.4%) 20-29 years (18.4%) 30-39 years (23.6%), 40-49 years (20.3%), 50-59 years (15.6%), and 60 years and older (20.7%)). 42% of the sample was female.

3.2 Measures

Dependent Variables. Data on intention to use and attitude toward use were obtained from the survey. The two items for intention to use and the four items for attitude toward use were derived from Davis (1989). All items were rated on a five-point Likert-type scale with anchors of "strongly agree" (1) and "strongly disagree" (5). The Cronbach's α scores of $\alpha = .82$ for intention and $\alpha = .91$ for attitude indicate very good reliabilities.

Independent Variables. Data on perceived usefulness and perceived ease of use was obtained from the survey. The four items for perceived usefulness and four items for perceived ease of use were derived from Davis (1989) and adjusted to fit the specific technology. The items were rated on a five-point Likert-type scale with anchors of "strongly agree" (1) and "strongly disagree" (5). Again, the measures showed very high reliabilities with Cronbach's $\alpha = .91$ and $\alpha = .94$, respectively. Subjective control was assessed using a five-item scale derived from Beier et al. (2006) on the basis of the original technology acceptance model by Davis (1989). All items were rated on a five-point Likert-type scale with anchors of “strongly agree” and “strongly disagree”. The measure also showed very high reliability with Cronbach’s $\alpha = .91$.

Control Variables. Data on gender (coded as 1= female and 2= male) and age (coded as 1= 18-19, 2= 20-29, 3= 30-39, 4= 40-49, 5= 50-59, 6= 60-69, and 7= 70-79) was obtained from the survey.

4 RESULTS

A regression approach proposed by Baron and Kenny (1986) to testing the hypothesized mediated relationships was performed using SPSS 17. . For supporting mediation according to Baron and Kenny (1986) four conditions have to be met:

(1) The independent variables must significantly account for variations in the mediator,

(2) the independent variables must account for variations in the dependent variable,

(3) the mediator must account for variations in the dependent variable, while

(4) the effects of the independent variables on the dependent variable decrease significantly when controlling for the mediator.

The fourth condition can be examined by Sobel’s (1982) test of indirect effects. To check whether multicollinearity contaminates the results, we examined the variance inflation factors (VIFs) for all independent and control variables included in the model. This procedure is widely used as the VIF is a good indicator of the extent to which the variance of a coefficient is increased due to collinearity among the variables. The highest VIF was 2.5. According to the guidelines provided by Neter et al. (1996) these statistics indicate that multicollinearity is unlikely to be problematic. Descriptive statistics are provided in Table 1.

	Variable	Mean	STD	1	2	3	4	5	6
1	Age	3.92	1.72						
2	Gender	1.57	0.50	.03					
3	Perceived Usefulness	1.87	0.86	.18 *	-.02				
4	Perceived Ease of Use	2.12	0.92	.47 *	-.08	.43 *			
5	Subjective Control	3.00	1.13	.24 *	.06	.36 *	.48 *		
6	Attitude toward use	1.85	0.82	.14 *	.04	.73 *	.47 *	.48 *	
7	Intention to use	2.46	1.05	.18 *	.02	.60 *	.46 *	.46 *	.72 *

Note. N = 212. * $p < .05$

Table 1. Means, standard deviations and correlations for study variables.

The estimates for the regression analyses are provided in Table 2. In all regressions the control variables (age and gender) were entered first. Equation 1 examines the relationship between perceived ease of use and perceived usefulness. As suggested by the original TAM, perceived ease of use significantly influenced perceived usefulness ($\beta = .42$, $p < .01$), thus supporting hypothesis 1. The following equations were calculated in order to examine the mediation hypotheses (Baron et al. 1986): First, the mediator was regressed on the independent variables (equation 2), second the dependent variable was regressed on the independent variables (equation 3), and third the dependent variable was regressed on both the independent variables and the mediator (equation 4) (cf. Dirks 2000, Kirkman et al. 2009). Whereas all three regressions are needed for examining the mediation hypotheses, only the third regression (equation 4) is necessary for examining hypothesis 5. The data provide support for hypothesis 5. After controlling for age, gender, perceived usefulness, perceived ease of use, and subjective control, attitude toward use had a significant effect on intention to use ($\beta = .70$, $p < .01$).

Equation	Variable: Dependent	Variable: Independent	β	t		R^2_{adj}
1	Perceived Usefulness	Age	-0.02	-0.49		0.18
		Gender	0.03	0.32		
		Perceived Ease of Use	0.42	6.35	**	
2	Attitude toward use	Age	-0.05	-1.88		0.59
		Gender	0.08	1.15		
		Perceived Usefulness	0.57	12.04	**	
		Perceived Ease of Use	0.15	2.81	**	
		Subjective Control	0.15	3.93	**	
3	Intention to use	Age	-0.02	-0.54		0.45
		Gender	0.06	0.56		
		Perceived Usefulness	0.55	7.55	**	
		Perceived Ease of Use	0.20	2.58	*	
		Subjective Control	0.20	3.54	**	
4	Intention to use	Age	0.01	0.34		0.54
		Gender	0.00	0.04		
		Perceived Usefulness	0.15	1.80		
		Perceived Ease of Use	0.10	1.43		
		Subjective Control	0.10	1.90		
		Attitude toward use	0.70	7.27	**	

Note: N = 212. ΔR^2= .09 in Step 3. p< .05. Degrees of freedom are 16, 62, 32, and 43 for Equations 1, 2, 3, and 4, respectively. * p < .05, ** p < .01

Table 2. Summary of regression analyses.

Thus, the third condition for the mediation hypotheses is satisfied. In equations 2 and 3, the first and second precondition for mediation are also fulfilled (see Table 2): Perceived usefulness, perceived ease of use, and subjective control do have a significant effect on attitude toward use (β = .57, p < .01; β = .15, p < .01; β = .15, p < .01) and on intention to use (β = .55, p < .01; β = .20, p < .05; β = .20, p < .01). When attitude toward use was added in equation 4 (β = .70, p < .01), the coefficients for perceived usefulness, perceived ease of use and subjective control decreased in magnitude (β = .15; β = .10; β = .10) and all became statistically insignificant (p > 0.05). Additionally, according to Sobel (1982) the significance of indirect effects was tested. The results (see Table 3) indicate that the indirect effects of the independent variables perceived usefulness (z = 10.82, p < .01), perceived ease of use (z = 7.01, p < .01), and subjective control (z = 6.93, p < .01) were highly significant, indicating that their effect on intention to use drops significantly once attitude is incorporated.

Variables	Indirect Effect	z
Perceived Usefulness → Attitude → Intention	.64	10.82**
Perceived Ease of Use → Attitude → Intention	.39	7.01**
Subjective Control → Attitude → Intention	.32	6.93**

Note: N = 212. ** p < .01

Table 3: Results of tests of indirect effects

Hence, the pattern of results provides support for attitude mediating the relationship between salient beliefs (perceived usefulness, perceived ease of use, and subjective control) and behavioral intention to use. Thus, hypotheses 2 – 4 are supported by our data. Attitude toward use and the control variables are found to account for a substantial portion of the variance in intention to use (R^2adj = .54).

5 DISCUSSION AND IMPLICATIONS

The findings of this study are consistent with the TAM in that perceived ease of use affects perceived usefulness and both variables are significant predictors of attitude toward use. Besides the variables from the original TAM the study also analyzed the influence of another decisive variable in the context of investigating acceptance in private settings, namely subjective control. This construct was also found to be a significant predictor of attitude toward use. In terms of the impact, subjective control was found to be the second-strongest predictor of attitude behind perceived usefulness. This finding is in line with previous research (Lederer et al. 2000, Venkatesh et al. 2000). Previous literature also suggests that the mediating effect of attitude on intention to use depends on the experience of the consumer with the technology (Kim et al. 2009), in that the more experienced the participants are, the higher the mediating effect of attitude. In our study, participants were not familiar with smart meters. But due to extensive use of audio-visual material in the survey, respondents were enabled to better assess and anticipate "hands-on" usage. Beyond that, study's participants had at least some experience with the internet as the survey was conducted online. In the survey's usage scenario the internet was assumed to act as an intermediary between smart meters and users in terms of providing usage information. We assume that these factors had a considerable impact on the full mediating effect of attitude found. Self-selection in the online survey might also in parts explain this effect. Participants taking part in the online survey might generally be more comfortable and experienced with new technologies than average customers. The study helps researchers to understand the relationships between the beliefs perceived ease of use, perceived usefulness, and subjective control and the acceptance of smart meters by users. It shows that the intention to use smart meters depends on the attitude of the potential user. Attitude toward use was found to fully mediate the influence of perceived ease of use, perceived usefulness, and subjective control and to explain a substantial amount of variance (ΔR^2adj between equation 3 and 4 is .09). The total model accounts for a substantial proportion of the variance (R^2adj = .54) in usage intention which is notably above the average variance (~30-40%) usually explained by TAM (Venkatesh et al. 2000, Lee et al. 2003).

A few limitations of this study are worth noting. First, we employed a correlational design, which limits our ability to draw causal inferences. Future research on the acceptance of smart meters may benefit by using other causal designs. Moreover, in this study we did not measure actual use of smart meters. Future research should investigate the relationship between intention to use and actual use of smart meters to gain further insights. Also longitudinal research designs should be employed to investigate actual usage over time (cf. Venkatesh 2000, Venkatesh et al. 2000) since the perception of a technology can change considerably while using it (Lee et al. 2003). In addition, examining other dependent variables such as satisfaction with the technology should be incorporated in future studies (Yang et al. 2004). Another limitation of our study is that we measured attitude as a single construct. We did not distinguish between affective and cognitive components of attitude as shown in recent studies (Yang et al. 2004). Further, studying potential antecedents (e.g., social influence, self-efficacy) of the salient beliefs incorporated in our model may provide further insights which factors drive smart meter adoption (cf. Bhattacherjee 2001, Devaraj 2002). Moreover, this study only investigated one country, namely Germany. Future research could investigate the acceptance and distribution of smart meters in more countries to account for cultural differences (cf. Straub 1994, Straub et al. 1997). This study gives insights into the TAM applied to the context of private usage of a new technology. Beside the outlined limitations, this research may be applied to similar settings where private usage is associated with a potential loss of control and the technology permeates everyday private life. Three important implications for practice and policy can be drawn from the study's results. First, the study has shown that subjective control significantly affects a person's attitude to use a smart meter. As private information is continuously transferred to other entities like grid operators or energy providers and automatic interventions in a demand response scenario occur regularly, both practitioners and policy makers have to take concerns about privacy seriously. Policy should ensure data security and integrity through effective privacy policies. Whereas grid operators, utilities and other involved market participants should explain consumers clearly and in detail what happens to their data and why these data are essential for leveraging the benefits of the smart metering technology and these of an e-energy system as a whole. Second, regarding the salient beliefs perceived usefulness and ease of use the participant's assessment in absolute terms is considerably high. The high estimation of usefulness might be explained by factors like environmental awareness and concerns regarding climate change. Regarding the influence of perceived usefulness, consumers' perception of smart meters' usefulness might be further increased by additionally providing value-added services (e.g., security or assistance services, home automation). Furthermore, user interfaces should be structured as clearly as possible to ensure easy and time-saving handling. Third, the private consumers' attitude toward the use of smart meters is highly positive and fully mediates the relationship with behavioral intention. However, changes in attitude are observed to occur more quickly in comparison to non-evaluative beliefs or values (Thompson 1996). Attitude is susceptible to influence from one's social environment, e.g., when others point out deficits or weaknesses of a technology (Thompson 1996). The variable attitude as measured in our study is empirically and conceptually different from attitude strength. Thus, the measured attitude - if not strong - can change rapidly (Yang et al. 2004, Kim et al. 2009). Regarding the temporary, unstable, and malleable nature of attitude, continuous efforts from policy and industry are needed to ensure a broad and sustained acceptance of the smart metering technology. Attitude might be positively affected by directly enhancing people's motivation (e.g., power saving competitions) and abilities or by pointing out smart metering technology's benefits through persuasive information campaigns (Yang et al. 2004). Moreover, as essential technologies already exist, we assume that open standards and interfaces along with time- and load-variable tariffs can boost smart meter's diffusion. That way, the traditional energy system characterized by passive and isolated components may develop to an interactive, decentralized, market- and service-based e-energy system in which new potentials and business models can emerge.

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