Adoption of Information Systems in the Electricity Sector: The Issue of Smart Metering

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ABSTRACT

Given increases in electricity consumptions, coupled with finite resources and technological advances, ICT-enabled electrical networks such as smart grids are increasingly being deployed by energy companies. One part of smart grids is smart meters, which are digital electrical meters, having the potential to increase energy efficiency in both residential and industrial sectors. However, a challenge to smart meter implementation in residential settings is acceptability and adoption by the end-users (or consumers). Despite the acknowledged challenges in smart meter adoption, little academic research has been conducted on this topic. This study attempts to contribute towards that by developing a model of SMT adoption (drawing on existing literature on adoption behaviors and motivational psychology) and testing it using a survey of German consumers. Results highlight the important role played by factors such as internal and external locus of control (among others) on consumers' intention to adopt SMT.

Keywords

Smart Meter, Smart Grid, Energy Informatics, Technology Adoption.

INTRODUCTION

Electricity consumption continues to grow worldwide (IEA, 2009). Finite resources, uncontrollable risks inherent to nuclear power, a rising environmental consciousness and rapid technological advancements in power engineering concepts for a sustainable energy supply and electricity grid attract more and more attention in public. Many initiatives aim to enhance energy efficiency, secure supply and mitigate climate change (e.g., Energy Independence and Security Act of 2007, 2009/72/EG). Business leaders are embracing environmental sustainability in their corporate vision and "Green IT" has become a buzzword for strategic technology. Consequently, within academia as well, Watson et al. (2010) highlight the need to introduce a new subfield to IS research called energy informatics, "that recognizes the role that IS can play in reducing energy consumption, and thus CO_2 emissions" (Watson et al., 2010, p. 24).

One domain of energy informatics is smart grids which are ICT-enhanced energy networks. One step towards smart grids is new electricity meters, called smart meters. The term refers to a digital electricity meter that allows bidirectional communication between the meter and an energy supplier. By providing information about current prices, energy consumption and energy production in the grid, the smart metering technology (SMT) allows better integration of decentralized energy distribution sources and intelligent distribution of large-scale power plants like offshore wind-farms. Furthermore, it enables services such as demand response, customer-oriented services and applications such as in-home displays, and other information- and convenience-based products. Therefore, SMT has the potential not only to increase the energy efficiency of the residential and industrial sector but beyond that to radically alter the way energy is produced and consumed by the wide range of new applications and services it facilitates (e.g., Potter et al., 2009). To fully realize the

benefits of the technology and justifying the massive investments, it is absolutely crucial that the end consumers adopt and use SMT and its services (e.g., Faruqui et al., 2010). Looking at the way how most utilities introduced their smart meters, it is noticeable that they didn't engage in programs informing their customers (Fox-Penner, 2010), about smart meters and its benefits. Consequently, there have been significant push-backs from consumers with respect to smart meters. Despite these challenges with respect to smart meter adoption, few academic studies have examined this issue. Our review of the literature within the IS discipline failed to provide a list of any meaningful studies examining this issue. A search of the broader literature base also resulted in few studies on smart meters. These studies have mainly examined issues such as demand response (e.g., Abrahamse et al., 2005), business models (e.g., Jagstaidt et al., 2011) or technical and design aspects (McDaniel and McLaughlin, 2009) with respect to smart meters, ignoring its adoption-related challenges.

Given the massive investments needed to establish a smart metering infrastructure, and the already existent protests against its first campaigns, it is absolutely necessary to further investigate the adoption of smart metering. This study attempts to contribute in this regard by taking a socio-technical perspective and examining consumers' behavior with respect to smart meter adoption. Such a perspective is especially relevant given the debates within the IS discipline regarding a stronger focus on socio-technical elements in our research. Thus, the specific research question that we examine is: *What are the determinants that affect the end-user acceptance of SMT in the residential sector?*

REVIEW OF THE EXISTING LITERATURE

Adoption Research

In the last decade, adoption research has helped us to understand a variety of antecedents of the adoption of information systems. In the beginning the main focus of adoption studies was on work-related technologies in organizational settings (e.g., Venkatesh et al., 2003). In the early 2000s, studies began to investigate technology adoption in private and residential settings (Brown, 2008). Besides the various technology-related aspects, these studies also investigated antecedents originating in the fields of marketing and social psychology such as trust and risk issues (e.g., Pavlou, 2003), social pressures (e.g., Venkatesh and Brown, 2001), and the role of values (e.g., Bagozzi, 1982). Hence, Venkatesh et al. (2003) stressed the need to do further research regarding system and information characteristics and the way in which they might indirectly shape system usage. Such characteristics are specifically more salient in the context of SMT, where possible financial and ecological benefits/incentives could shape the users' behavior. Below, we discuss this in further detail.

Incentive Alignment and Motivation Theories

Ba et al. (2001) stress the need to introduce a new dimension to IS research which they call incentive alignment. Incentive alignment is "when the system has embedded features that induce its users to employ the system in a manner consistent with the design objective, and hence the organization's overall goals" (Ba et al., 2001, p. 227). In the case of SMT, variable tariffs offer this opportunity.

Simultaneously, environmental aspects are also becoming more important in our society (Poortinga et al., 2006). Therefore, focus only on incentives is not sufficient. Motivation psychology takes a broader lens to identify the triggers of certain behaviors, and explores the whole spectrum from external to internal behavioral triggers. There are several motivation-related theories that may be drawn upon to examine adoption. The self-determination theory (SDT) focuses on the reasons individuals have for engaging in different tasks. The organismic integration theory (OIT), a subtheory of the SDT, splits the motivation for an externally induced behavior in a range from amotivation, to passive compliance, to active personal commitment. It explains these different motivations with the level of internalization and integration of the values and regulation of the induced behavior. The SDT considers extrinsic motivation to vary greatly in its relative autonomy (Ryan and Connell, 1989).

Using SMT due to environmental reasons is neither extrinsic, nor intrinsic motivation. It is much more a case of identified regulation, where the device is used to achieve progress in another area (e.g. environmentalism). Other incentives as possible savings through variable tariffs are farther left on the continuum and reflect the case of externally regulated behavior. Therefore using the continuum of motivation offers researchers the possibility to get a much deeper understanding of how these different incentives and reasons influence the adoption of SMT.

Environmentalism and Privacy Risk

Environmentalism may be defined behaviorally as "the propensity to take actions with pro-environmental intent"(Stern, 2000, p. 411). Pro-environmental behavior can be seen as a mixture of self-interest and concern for others (e.g., Hines et al., 1987). Researchers focusing on pro-environmental behavior as pro-socially triggered, often apply the norm-activation model

(NAM) (Schwartz, 1977), whereas researchers focusing on the motive of self-interest tend to use rational choice and expectancy-value models such as the theory of planned behavior (TPB) (Ajzen, 1991).

Every time personal data is transferred, privacy and data security issues also arise. These issues are widely discussed in the context of smart-metering (e.g. McDaniel and McLaughlin, 2009). Several governments and companies, e.g. the Netherlands, PG&E already had to stop the roll out of smart meters, because consumer groups raised privacy concerns. Similar problems have been extensively examined in the fields of e-business.

Perceptions of risk inherent in product adoption and usage in commercial relations have been studied for many years (Bauer, 1967; Dowling and Staelin, 1994). Perceived risk can be defined as "a combination of uncertainty plus seriousness of outcome involved" (Bauer, 1967). It is relevant in information system adoption decisions when e.g., feelings of uncertainty, discomfort and/or anxiety (Dowling and Staelin, 1994) and conflict arouse in the consumer (Bettman, 1973). This dissonance emerges from different perceptions and weighting of benefits and costs. Cunningham (1967) divided perceived risk into six dimensions: performance, financial, opportunity/time, safety, social and psychological loss. Featherman and Pavlou (2003) summarize seven very similar facets of perceived risk in their work.

CONCEPTUAL MODEL

Based on differences between SMT and other technologies studied in earlier household adoption settings (e.g., Brown and Venkatesh, 2005; Venkatesh and Brown, 2001), we had to draw on different theoretical bases. While several theoretical perspectives made sense, we decided to take a motivational perspective, as it allows including societal and financial incentives which play an important role in the area of smart metering. Malhotra et al. (2008) developed a model, that offers a combination of the technology adoption and motivation literature aspects. Therefore, we propose to apply a modified version of this adoption model (see Figure 1). It was developed based on the premise that the impact of external stimuli and social influences captured through variables such as subjective norm and managerial mandates in IT adoption research is no longer valid (e.g., Bhattacherjee and Sanford, 2006). The same external influences and stimuli have different effects on different users, such that some of them are willing to adopt a system while others are not (e.g., Davis et al., 1992). Hence, an endogenous theoretical understanding – that is, how users' internal perceptions of autonomy, freedom, conflict and feelings of external pressure affect intentions – is applied in the model. The model is based on the TAM (Davis et al., 1989) and the Organismic Integration Theory (OIT) (Deci and Ryan, 1985). The OIT allows understanding how a user's internal psychological perceptions about autonomy shape his or her intentions and behaviors. Hence, it can help explain why some technologies are more readily accepted by some users than by others. Focusing on this endogenous perspective instead of following the dichotomy of extrinsic vs. intrinsic motivation, allows capturing a large base of motivational constructs especially important in the area of SMT where pure intrinsic motivation seems to play a minor role compared to different facets of extrinsic motivations (societal vs. financial incentives).

Similar to Malhotra et al. (2008), and other adoption studies, we rely on intention as dependent variable since "intention is the most proximal influence on behavior and mediates the effect of other determinants on behavior" (Venkatesh and Brown, 2001, p. 76). Based on our earlier literature review, we integrate several other new variables to the model, making this paper especially relevant to the case of SMT adoption. We therefore propose to add perceived behavioral control to the model, as it adds an important facet out of the environmental behavior literature to the study and enriches our understanding of the extent to which users feel in control to adopt and use SMT. This is especially important as new variable tariffs could be associated with financial constraints by the customers. Furthermore, we propose to include perceived privacy risk, given that both academic and practitioner outlets have identified privacy issues as one of the main inhibitors of SMT adoption. We think that these two new variables offer insights in the adoption of smart metering.

Adoption Literature

Based on belief-attitude-behavior models of the theory of reasoned action (Fishbein and Ajzen, 1975), Davis et al. (1989) suggested that perceived ease of use and perceived usefulness predict intentions to use. Perceived ease of use influences behavioral intentions through two causal pathways: indirectly through perceived usefulness, and through attitude. Hence, we contend:

Hypothesis 1: Perceived usefulness of SMT positively influences the attitude towards SMT.

Hypothesis 2: Perceived ease of use of SMT positively influences the attitude towards SMT.

Hypothesis 3: Perceived ease of use of SMT positively influences perceived usefulness of SMT.

Hypothesis 4: Attitude towards SMT positively influences the intention to use SMT.

Perceived Locus of Causality

PLOC pertains to the self. It refers to the degree to which action is initiated and endorsed by the self and therefore describes the relative autonomy of the act (Ryan and Connell, 1989). Users may feel compulsion due to feelings of guilt or obligation even when external pressures (e.g., social norms) are clearly absent. Hence, user's perceptions of volition and compulsion can be understood as functions of PLOC (Malhotra et al., 2008). Compulsion is characterized as an external PLOC while an internal PLOC refers to volition. The different types of PLOC have qualitatively different influences on behavior and have a cumulative effect on intentions (Deci and Ryan, 1985). The OIT allows examining different feelings of autonomy and external pressure and their combined effects on behavior. Therefore, different types of endogenous motivation characterize different PLOCs.

The **internal PLOC** is depicted by the intrinsic and the identified PLOC. Both states are characterized by feelings of volition. The intrinsic PLOC refers to behavior that is spontaneous and performed for inherent fun, whereas the identified PLOC refers to behavior based on personal values and goals and outcomes (Ryan and Connell, 1989). Although the associated behavior is performed freely, it results from internalization and integration of external regulations and is, in contrast to the internal PLOC, a type of extrinsic motivation. As it is volitional, and focused on regulations, values and outcomes, it helps explain why some social values and norms are accepted by individuals while others are not. The effect of volitional extrinsic behavior is similar to behavior associated with intrinsic motivation (Deci and Ryan, 1985). Hence,

Hypothesis 5a: Consumers' internal PLOC positively influences their intention to adopt SMT.

Attitude can be seen as the user's evaluation (positive or negative) about performing a specific behavior (Fishbein and Ajzen, 1975). When internally motivated, the performed behavior is normally personally important and associated with positive feelings of volition, freedom and autonomy. Hence,

Hypothesis 5b: Consumers' internal PLOC positively influences their attitude towards SMT.

When people feel coerced to adopt and execute a certain behavior, the associated psychological feelings can be as enervating as bearing a physical burden, whereas if executed volitionally it would feel effortless and easy (Csikszentmihalyi, 1990). Thus,

Hypothesis 5c: Consumers' internal positively influences their perceived ease of use of SMT.

Individuals may often evaluate performance in terms of what they deem personally meaningful or contributing to personal development (e.g., Sternberg, 1999). They tend to look favorably upon it, if it includes personally meaningful activities. Hence,

Hypothesis 5d: Consumers' internal PLOC positively influences their perceived usefulness of SMT.

External PLOC is associated with perceived reasons for one's behavior that is attributed to external authority or compliance (Ryan and Connell, 1989). It represents the least autonomous form of extrinsic motivation and it is assumed that there is no conflict between the perceived external influences and personal values of the user. This leads to behavior that is typically performed to satisfy external demands. Thus,

Hypothesis 6a: Consumers' external PLOC positively influences their intention to adopt SMT.

Non-spontaneous behavior can be promoted by external incentives (Deci and Ryan, 1985). Depending on these rewards, the evaluation of performing a specific behavior can change and the reward can substitute for positive feelings otherwise associated with autonomy and freedom. Hence,

Hypothesis 6b: Consumers' external PLOC positively influences their attitude towards SMT.

If an activity is not fully self-endorsed, the execution of a behavior may feel coerced or pressured when motivated by external rewards (Deci and Ryan, 2002). However, if the given incentive is personally meaningful, the behavior may still feel more autonomous and easier (Deci and Ryan, 1985). This is likely to happen in the context of smart meters. Hence,

Hypothesis 6c: Consumers' external PLOC positively influences their perceived ease of use of SMT.

Usefulness is perceived differently amongst users. Some may perceive it in the instrumentality of job performance, while others may perceive it in the development and the growth of the self. Individuals often perceive external incentives as useful when they are not deemed as coercive (Deci and Ryan, 1985). Thus,

Hypothesis 6d: Consumers' external PLOC positively influences their perceived usefulness of SMT.

Perceived Behavioral Control

Perceived behavioral control reflects perceptions of internal and external constraints on behavior (Ajzen, 1991). Thus,

Hypothesis 7: Consumers' perceived behavioral control positively influences their intention to adopt SMT.

Perceived Privacy Risk

Perceived privacy risk refers to the potential loss of control over personal information, such as when information about one is used without ones knowledge or permission (Featherman and Pavlou, 2003). Hence,

Hypothesis 8: Consumers' perceived risk with respect to privacy loss will negatively influence their intention to adopt SMT.

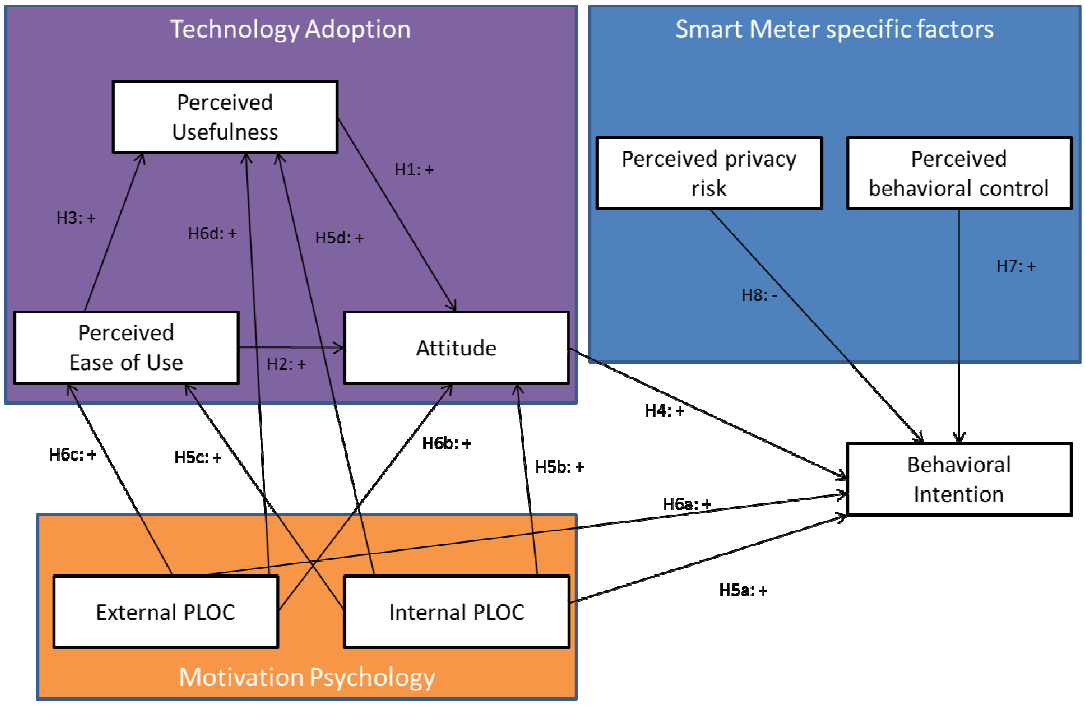

Figure 1. Structural Model

RESEARCH METHODOLOGY

An online based survey of German consumers was chosen to test the predicted relationships within the model. As SMT is still in its infancy in Germany, and therefore hardly known to citizens, we needed to shortly illustrate the technology in order to establish a common technological understanding amongst all participants.

Sample

We are relying on a professionally recruited panel of respondents for our study. The sample consisted of German citizens (co-)responsible for energy decisions in their own household. Given the ambitious targets in the share of renewable energy in the energy mix as well as the phase out of the nuclear power, and the expected congestion in the German transmission network (Veit et al., 2009), made Germany a particularly interesting region for an empirical investigation of the adoption of smart meters in private households. Overall, 1.173 citizens all over Germany were invited via email to participate in the survey. Uncompleted questionnaires and questionnaires with implausibly short handling time were removed from the sample. 374 completed questionnaires were used for the analysis, resulting in a response rate of 34.88%. The participants' age ranged from 20 to 80 (mean: 49.77) with 47.33% males and 52.67% female respondents.

Measures

The TAM constructs (Intention, Attitude, Perceived Usefulness and Perceived Ease of Use) were measured using an adapted scale by Davis et al.'s (1989). For the PLOC scales, we used the measurement instruments suggested by Ryan and Connell (1989). These abstract measures were combined with self-developed items to create a better fit to the smart metering context.

To measure perceived behavioral control, we used the scale by Venkatesh et al. (2003) as perceived behavioral control and perceived usefulness were tested simultaneously in their model. Perceived privacy risk was measured with adapted instruments provided by Featherman and Pavlou (2003). The items were validated following the qualitative and quantitative procedures proposed by Moore and Benbasat (1991).

Analysis

SmartPLS was used for analyzing the data. In assessing the validity of our instruments using the PLS-approach, we relied on prior/recent research using PLS (e.g., Hulland, 1999). Table 1 shows that the composite reliabilities of all the constructs are over 0.7 and the AVEs of all the constructs are over the threshold value of 0.5. This established the convergent validity of our items. Discriminant validity was established by examining the correlation between the latent variable scores with the measurement items, and ensuring that the measurement items load higher on their "assigned factor" than on other factor items (Gefen and Straub, 2005). We re-confirmed discriminant validity by ensuring that the square root of the AVE of a construct exceeded all correlations between that factor and any other construct within the study (e.g., Fornell and Larcker, 1981) (see Table 2).

Convergent Validity	AVE	Composite Reliability
Attitude	0.79	0.94
External PLOC	0.60	0.86
Internal PLOC	0.68	0.91
Intention	0.87	0.95
Perceived Behavioral Control	0.69	0.87
Perceived Ease of Use	0.76	0.91
Privacy Risk	0.69	0.87
Perceived Usefulness	0.84	0.95

Table 1. Convergent Validity

Discriminant Validity	Attitude	EPLOC	IPLOC	Intention	PBC	PEOU	PR	PU
Attitude	0.89							
EPLOC	0.58	0.78						
IPLOC	0.66	0.68	0.83					
Intention	0.67	0.60	0.73	0.93				
PBC	0.23	0.21	0.31	0.31	0.83			
PEOU	0.41	0.40	0.46	0.46	0.61	0.87		
PR	-0.22	-0.24	-0.26	-0.24	-0.20	-0.17	0.83	
PU	0.58	0.56	0.67	0.58	0.34	0.44	-0.29	0.92

Table 2. Discriminant Validity

In the next phase of our analysis, we examined the significance and strength of our hypothesized relationships. Results of the path analysis, including the path coefficients and path significances are shown in Table 3. The variance explained of the dependent variables is shown in brackets behind them.

Overall the model was able to explain about 61.1% of the variance of the individual's intention to adopt SMT.

Hypothesis	β	P	Supported or not
H1: Perceived Usefulness (R^2=48.4%) -> Attitude (R^2=49.7%) (+)	0.184	$p < 0.01$	supported
H2: Perceived Ease of Use (R^2=22,5%) -> Attitude (+)	0.083	$p < 0.1$	supported
H3: Perceived Ease of Use -> Perceived Usefulness (+)	0.143	$p < 0.01$	supported
H4: Attitude -> Intention (R^2=61.1%) (+)	0.307	$p < 0.01$	supported
H5a: Internal PLOC -> Intention (+)	0.411	$p < 0.01$	supported
H5b: Internal PLOC -> Attitude (+)	0.371	$p < 0.01$	supported
H5c: Internal PLOC -> Perceived Ease of Use (+)	0.351	$p < 0.01$	supported
H5d: Internal PLOC -> Perceived Usefulness (+)	0.477	$p < 0.01$	supported
H6a: External PLOC -> Intention (+)	0.125	$p < 0.05$	supported
H6b: External PLOC -> Attitude (+)	0.193	$p < 0.01$	supported
H6c: External PLOC -> Perceived Ease of Use (+)	0.184	$p < 0.01$	supported
H6d: External PLOC -> Perceived Usefulness (+)	0.160	$p < 0.01$	supported
H7: Perceived Behavioral Control -> Intention (+)	0.079	$p < 0.05$	supported
H8: Perceived Privacy Risk -> Intention (-)	-0.019	$p > 0.10$	not supported

Table 3. Path Coefficients and Significance

DISCUSSION AND IMPLICATIONS

Practitioners and researchers (e.g., Watson et al., 2010) stress the need to understand consumers' adoption decisions in the field of energy informatics. This study offers new insights into the adoption behavior of SMT by examining how motivational states and incentives, perceived behavioral control, perceived privacy risk and technical factors as perceived usefulness and ease of use influence the intention to adopt it.

Our results indicated that internal PLOC had a strong effect on users' intention. Opposed to the extrinsic–intrinsic dichotomy that often treated extrinsic motivation in terms of external rewards, and in contrast, considered intrinsic motivation as being innate, the continuum of motivation allows focus on the volitional basis of internal PLOC. In our case, although not innate (intrinsic), some (identified) social values such as environmentalism seem to be internalized and consequently acted as forcefully as intrinsic motivation. This finding reflects the growing importance of environmental aspects in today's societies. The external PLOC was found to have a significant impact on users' intentions too. But compared to the internal PLOC, the effect is much weaker. Both motivational influences had a strong significant effect on the users' attitude. Furthermore, the internal PLOC had a very strong positive effect on perceived usefulness and perceived ease of use, whereas the external PLOC again had a smaller impact.

Interestingly, the effect of perceived privacy risk was found to be weak and insignificant. On the one hand, especially regarding moratoriums and consumer protection groups and the media's echo, perceived privacy risk would have been expected to be a strong influencing factor. On the other hand, small groups that feel ignored by major companies start organizing into an opposition and thereby, catching the media's attention.

Perceived behavioral control was found to be significant. This implies that the more respondents feel in control over adopting SMT the higher are their intentions to do so. This could be particularly the case because the deployment of SMT in Germany is still in its infancy and not obligatory.

Consistent with TAM, perceived ease of use affects perceived usefulness and both were found to be significant as predictors of attitude towards SMT. The very small effect of perceived ease of use on attitude towards SMT could be explained by the fact that our sample comprised of would-be (or intended to be) users of SMT, and not users who has had significant experience with this technology, and also by the fact that technology itself is still in its infancy therefore providing consumers with little exposure. Finally, attitude was found to be a significant and strong predictor of users' intention to adopt SMT.

The findings of the study must be interpreted in light of its limitations. Germany has a long tradition of anti-nuclear energy demonstrations and was the only country that started to phase out of nuclear energy after the melt down of the reactors in Fukushima. Hence, a German sample could cause a stronger acceptance of SMT due to identified social values, that is, environmentalism. Consequently, future studies involving samples from other countries will need to be conducted to show if generalizability to other countries is given.

CONCLUSION

In summary, our study has helped shed light on the determinants of SMT adoption, a topic that has received scant attention from researchers till date. Our research model applied an endogenous point of view that allowed us to understand how users perceive their own reasons for acting and the relation of such reasons to self-perceived feelings of autonomy (Ryan and Connell, 1989). Understanding how endogenous motivations influence user intentions, beliefs, and behaviors is important for both theoretical and practical reasons. Furthermore it offers new insights into the adoption process of green products. From a practitioners' point of view the model can help to identify effective strategies to address and motivate customers to use and adopt SMT by supporting and facilitating their endogenous tendencies. Such strategies are expected to lead to a more persistent and better behavioral performance.

Therefore, future research needs to verify the results and continue developing our understanding of SMT adoption in the residential sector.

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