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RESEARCH ARTICLE

ADOPTION OF SUSTAINABLE TECHNOLOGIES: A MIXED-METHODS STUDY OF GERMAN HOUSEHOLDS[1]

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Although technologies spurred by the "Internet of things" are increasingly being introduced in homes, only a few studies have examined the adoption or diffusion of such household technologies. One particular area of interest in this context is electricity consumption, especially the introduction of smart metering technology (SMT) in households. Despite its growing prominence, SMT implementation has met with various challenges across the world, including limited adoption by consumers. Thus, this study empirically examines the antecedents of SMT adoption by potential consumers. Using a mixed-methods design, the study first unearths the SMT-specific antecedents, then develops a contextualized model by drawing on theories from motivational psychology and the antecedents identified earlier, and finally tests this model using a large-scale survey of German consumers. The results provide support for many of the hypotheses and highlight the importance of motivational factors and some household demographic, privacy, and innovation-related factors on consumers' intention to adopt SMT.

Keywords: Household technology adoption, smart meter technology, mixed methods, motivational psychology, sustainability

Introduction

Increasingly, technologies spurred by the "Internet of things" are being specifically designed and developed for household customers. However, few studies have examined the adoption or diffusion of household technologies (Venkatesh and Brown 2001; Venkatesh et al. 2012), resulting in gaps in our understanding of why and how consumers adopt (or do not adopt) such novel (and often complex) technologies (see Appendix A). The "complexity and evolving nature" of household technologies make their adoption more difficult (Shih and Venkatesh 2004, p. 59), leading to calls for more research on this topic, including examining technology adoption issues in new and novel contexts (Venkatesh, Thong, and Xu 2016). One such new area of interest within the household technology context is that of smart electricity consumption, with emphasis on the deployment of *smart meters* in households. Smart meters are digital electricity meters that allow bidirectional (or two-way) communication between the meter (installed in a home) and an energy supplier through smart metering technology (SMT). To fully realize the benefits of SMT and justify the massive investments it requires, it is critical for the technology to be adopted by consumers (Faruqui et al. 2010; Honebein et al. 2009).

Existing studies on SMT adoption have approached the topic from just a social point of view by either applying the lens of environmental friendliness and goal-framing or shared benefits and privacy issues (e.g., Kranz et al. 2010; Warkentin et

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al. 2017; Wati et al. 2011). In other words, they have applied a narrow lens to examining adoption-related issues (see Appendix A). Others have tested generic adoption models, such as the unified theory of acceptance and use of technology, in this context without focusing specifically on the SMT context within households (Toft et al. 2014; Wunderlich et al. 2013). We believe that a contextualized approach can enrich (and help in a deeper) understanding of SMT adoption (e.g., Hong et al. 2014). Thus, our objective *is to understand the salient factors that affect household adoption of SMT.* Further, a focus on SMT adoption responds to calls to further understand the role that IS can play on sustainability (Elliot 2011; Watson et al. 2010).

Given our focus on SMT-specific factors that affect adoption, and in the absence of any SMT context-specific adoption study, we relied on a mixed-methods empirical design. Such designs are appropriate when prior research on a topic is either fragmented or missing, as is the case here (Venkatesh, Brown, and Sullivan 2016). In developing our contextualized understanding of household adoption of SMT, we followed guidelines for single-context theory contextualization (Hong et al. 2014). We first identified general theories that may help in understanding household adoption of SMT and then used qualitative data to contextualize the theory by adding SMT-specific constructs. Finally, we incorporated the contextualized factors as antecedents of the dependent variables. By following this structured approach, we hope to contribute to the development of an empirically validated and contextualized model of SMT adoption in households.

Smart Metering Technology (SMT)

SMT requires smart grids, which are electricity grids enhanced with information and communication technologies (ICT). A smart grid collects, processes, and analyzes data on power generation, transmission, distribution, and consumption in real time, and therefore is expected to provide a wide range of benefits across the entire electricity value chain (e.g., Faruqui et al. 2010; Potter et al. 2009). The smart grid is visible to the residential customer through SMT, which consists of two products. The first product is a digital electricity meter installed in the residence and can be considered as the tangible technological artifact or good (e.g., Freiden et al. 1998; Xu et al. 2010). The meter allows the customer to access consumption information and helps to identify the so-called "power eaters" at home. A second device, provided along with the meter, is the smart box, which processes electricity cost and availability information for the energy provider, thereby communicating consumer-level energy use. The benefits of SMT to the customer include increased awareness of their energy use, the possibility of identifying ways to save energy, enhanced efficiency through better management options, and a set of innovative services and applications. Importantly, customers need to adopt only the meter and the box, and are not required to adopt any of the services, although the services are needed to realize actual benefits and value. In most instances, the services and information capabilities have not been fully realized, with the result being that the adoption of the devices is based primarily on the expectation of future capabilities rather than being based on trial use. Thus, several key factors customarily related to adoption, such as ease of use, are not relevant in this context. It is also important to note that the installation of the meter and the box causes some loss of privacy for consumers because power use, loads, and so on are communicated to the provider (Faruqui et al. 2010). In this study, we focus on the adoption of the entire SMT (i.e., meter and box), including its promise of future service capabilities.

Literature Review

Research on Household Technology Adoption

Technology adoption has been a key area of IS research, which has focused primarily on understanding the antecedents of behavioral intention (for an overview, see Venkatesh et al. 2007, Venkatesh, Thong, and Xu 2016). While early studies on this topic investigated the adoption of technologies within organizational settings (e.g., Venkatesh et al. 2003; Williams et al. 2009), later studies began to examine technology adoption in household settings (Brown 2008), such as the adoption of PCs, the internet, or even broadband (e.g., Brown and Venkatesh 2005; Brown et al. 2015; Hsieh et al. 2008; Venkatesh and Brown 2001; Venkatesh et al. 2012).

Some studies outside of the IS discipline have examined the adoption of green electricity (e.g., Arkesteijn and Oerlemans 2005) and energy-efficient practices at home (e.g., Mills and Schleich 2012). Such research has mostly focused on understanding the effect of demographic factors such as education, age, and household composition, although some scholars have considered the effects of utilitarian, hedonic, and social factors to explain household adoption of technologies (Brown and Venkatesh 2005; Brown et al. 2006; Venkatesh and Brown 2001). Other studies have highlighted various factors affecting household adoption of technology, ranging from innovativeness to willingness to pay, trust, and self-efficacy, among others (e.g., Arkesteijn and Oerlemans 2005; Hsieh et al. 2008; Shih and Venkatesh 2004).

Our review of the literature (see Appendix B) revealed several issues. First, despite a large number of household technologies being introduced in the last few years, there have been few studies on this topic since 2008. Second, studies have primarily examined the adoption of more generic technologies, such as PCs or the internet, where the attitude–intention–behavior linkages have been found to hold and which may not explain the adoption of SMTs due to their unique combination of being (1) a *tangible good* (the smart meter device that is installed at a consumer's residence with an attached gateway or box), (2) *innovative services and applications,* such as different price structures and demand management that have not been fully realized yet, but will be available to consumers in the near future, and (3) an *information provider* about eletricity usage, etc. (e.g., Frederiks et al. 2015). Third, SMTs bring more demand-side participation by introducing customers to different types of pricing, such as time-in-use pricing, real-time pricing, and critical-peak pricing (Haney et al. 2009). Although these different types of pricing seem advantageous for customers, the devices that help provide such pricing have associated costs, thereby expanding consumers' dilemma regarding adoption (e.g., Haney et al. 2009).

Fourth, the adoption of SMT raises certain privacy concerns owing to the bi-directional communication between the box installed at the consumer's home and the energy supplier. Conceivably, suppliers could extract data from SMT usage about behavioral patterns and habits, as well as socio-economic status (e.g., income and social class), which consumers may wish to keep private (Beckel et al. 2014, p. 409). This further complicates the adoption of such devices.

Finally, the current status of most smart meters is such that, at this time, all that the household consumers need to adopt is the "box" and it is not mandatory to adopt all other services and features. In the absence of more interactive usage surrounding the technology, many of the traditional adoption variables, such as ease of use (which have been studied in the context of the adoption of general household technologies), are not that salient. Instead, of most importance are consumers' internal motivations and their zeal in taking advantage of the different capabilities of this technology in the future. This prompted us to turn to motivational theories as our general overarching theoretical foundation (Hong et al. 2014).

Motivational Theories

Motivational psychology argues that the primary triggers of behavior are individuals' motivations, which can be either intrinsic or extrinsic (e.g., Deci 1971). One of the most widely used motivational theories is the organismic integration theory, which views motivation as being the level of internalization and integration of the values and regulation of the induced behavior (Ryan and Connell 1989). The concept of perceived locus of control (PLOC) is critical in this area (Ryan and Deci 2000). Within the IS field, researchers argue that motivation can range from *external PLOC*, which is characterized by feelings of compulsion, to *internal PLOC*, which is characterized by feelings of volition, to *introjected PLOC,* which is characterized by feelings of misalignment of perceived social influences and personal values (Malhotra et al. 2008).

Importantly, this model was tested on technologies used in the workplace or educational settings, whereas SMT is used primarily in residential settings, has concepts of innovative technology and environmental awareness embedded in it, and thus is likely to evoke some different sets of behaviors (Frederiks et al. 2015). Further, a context-specific study must consider relevant contextual variables (e.g., Hong et al. 2014; Johns 2006). Thus, we believe that a contextualized version of the earlier model is more suitable. To make the model contextualized, and given the nascent state of research on SMT, we conducted a qualitative study as part of the first phase of our mixed-methods design (Venkatesh et al. 2013; Venkatesh, Brown, and Sullivan 2016).

The Mixed-Methods Design

Mixed methods "contain elements of both the quantitative and qualitative approaches" (Tashakkori and Teddlie 1998, p. 5). In the IS field, where the nature of the context changes frequently and researchers often have difficulty drawing significant insights from existing theories and perspectives, mixed-methods designs are particularly useful (Venkatesh et al. 2013). Mixed-methods designs offer three benefits: the ability to "address confirmatory and explanatory research questions," to "provide stronger inferences than a single method or worldview," and to "produce a greater assortment of divergent and/or complementary views" (Venkatesh, Brown, and Sullivan 2016, p. 437). Given the general paucity of studies on SMT and our objective of uncovering and confirming the effect of SMT context-specific factors on adoption, such a design is well suited to our work.

We started by articulating three research questions (one qualitative, one quantitative, and one mixed-methods) (see Appendix C) (Venkatesh, Brown, and Sullivan 2016). We chose a "developmental" purpose whereby we conducted a qualitative study first and used the results from this "strand" to develop the hypotheses and the research model tested in the second strand of research (Creswell et al. 2008; Tashakkori and Teddlie 1998; Venkatesh, Brown, and Sullivan 2016; Venktesh et al. 2013). In terms of our epistemological strand, our study followed multiple paradigms, subscribing to the interpretive perspective during the qualitative study phase, and a more deductive stance during the quantitative phase. Our overall methodology may be seen as "mixed-methods multistrand" (Venkatesh, Brown, and Sullivan 2016, p. 443) with a "sequential exploratory design" (Creswell et al. 2008, p. 68). Our study also falls within the realm of "dominant–less dominant design" with the deductive quantitative paradigm being the dominant approach (Tashakkori and Teddlie 1998, p. 44). Our sampling strategy and data analysis involved a sequential design. Specifically, the research model for the quantitative study was built from the results of the qualitative study. In Appendix C, we elaborate on our decision choices surrounding the mixed-methods design. In Appendix D, we show how we followed established criteria for mixed-methods designs. See Figure 1 for the different phases of our study.

Phase 1 Qualitative Study

Our qualitative study, conducted in Germany, sought to answer the following question: *What salient factors determine household adoption of SMT?* To answer this question, we interviewed 24 individuals (Appendix E) identified through purposive sampling. Specifically, we used personal contacts and selected key people, including some who were members of working groups in the grid-operating and the supply and marketing divisions of large German energy suppliers and energy consulting companies, with knowledge of the electricity sector and the role of SMT. Participants were all either potential adopters or current consumers of SMT and were also household heads responsible for making SMT adoption decisions in their homes. It is argued that individuals who adopt energy efficiency-related technologies are typically employees of "technology-savvy companies" or work in related technology companies (Venkatesh 2008). In light of this, we believe that the sample for the qualitative part of the study was representative.

Interviews lasted from about 30 minutes to an hour and were conducted in German. We used a combination of open-ended and closed questions (Appendix O presents the interview guide). The majority of the interviews (that is, 17) were recorded, transcribed, and translated into English post-transcription. In a limited number of cases (that is, 7), the interviewee declined to be recorded and detailed notes (including entire quotes) were taken. We would like to note that detailed and "synthesized" field notes are viewed as legitimate sources of data and can be subjected to the same level of coding as recorded interview transcripts (Miles and Huberman 1994).

In our analysis, we did not quantify the interview data but used an inductive method to make sense of our data (Glaser 1992; Glaser and Strauss 1967). Sensitized by the review of existing literature on related topics, we approached the coding phase with a "start list" of codes (Miles and Huberman 1994, p. 58). We used constant comparative analysis to identify initial concepts and attempted to link these evolving sets of concepts to higher level categories (Charmaz 2000). This approach is consistent with the open coding phase of grounded theory methodology. Specifically, the open coding was conducted through the following steps. A list of codes was generated from the data through the use of the software Atlas.ti. Next, the three researchers, through further review of the translated transcripts, detailed field notes (where applicable), and constant comparison, created "abstract categories" of labels/codes by assigning labels to similar multiple observations (Miles and Huberman 1994, p. 58). The use of only the open coding phase has been suggested to be valid by previous studies (e.g., Sarker et al. 2002). In Appendix F, we provide the dominant open codes and show which of the respondents mentioned that concept. We also highlight the higher-order category generated from each of the open codes. In Appendix G, we provide illustrative quotes for each of the open codes.

Our initial coding of the data indicated the role of different types of motivation-related variables, ranging from financial incentives and social and political pressures to those developing from the interviewee's interest in ecological and environmental sustainability (see Appendices F and G). Our data also revealed that the characteristics of the consumers themselves played a major role. Age and income were repeatedly viewed as important, consistent with the general literature on household technology adoption. Household size also seemed to have a strong potential effect. Another consistent factor was the education of the potential consumers. As we uncovered these variables, we labeled these factors as the *household demographic characteristics.*

In addition, *electricity consumption-related factors* emerged as being important, especially average household electricity consumption and average electricity cost. While the average costs of electricity are conceivably tied to the average electricity consumption, our interviewees seemed to emphasize that the amount of consumption itself was a distinct factor that needs to be considered. Interestingly, our interviewees also stressed that the number of times customers have switched electricity providers is important in SMT adoption.

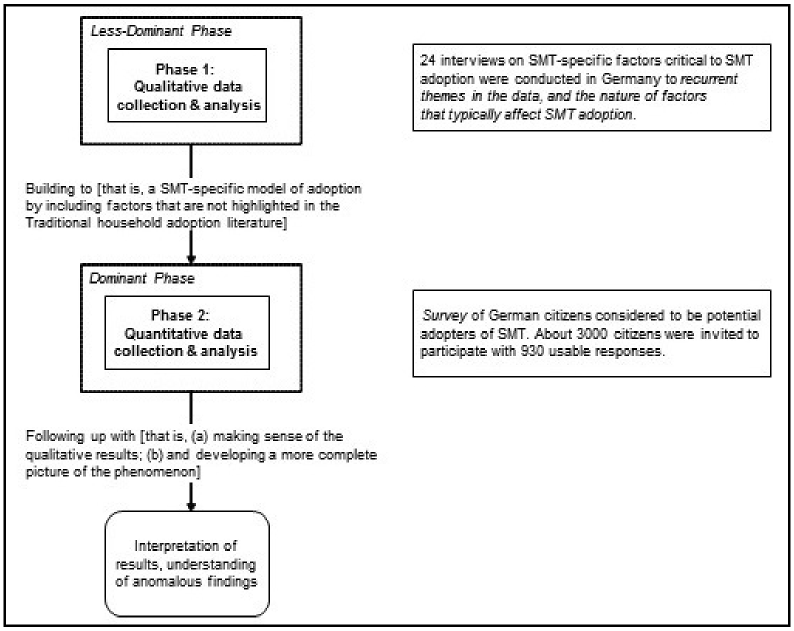

Figure 1. Sequential Dominant–Less Dominant Exploratory Mixed-Methods Design

As we have discussed, even a simple SMT device installed at a consumer's residence can potentially lead to some loss of privacy because it conveys power usage. Indeed, privacy concerns were raised by our interviewees. In addition, *perceptions of risk* related to a violation of privacy are likely to surface. Risk has been discussed widely in the context of SMT (e.g., McDaniel and McLaughlin 2009), and smart meters have "the potential to be a 'spy in the home'" and "allow governments to monitor household behaviors" (McKenna et al. 2012, p. 807). Our interviewees suggested the likelihood of privacy risk, with one interviewee expressing concern about the fact that data are shared from the customer to the supplier.

Further, the level of interest customers had for a new technology was seen as important. The literature suggests that individuals' level of interest in a new technology is similar to "use innovativeness" (e.g., Shih and Venkatesh 2004), which comprises of the curiosity/interest of the consumer in new technologies and the creativity of using technologies in novel ways (Price and Ridgway 1983). Although the consumer has little flexibility in using SMT in new and novel ways, the curiosity/interest of the consumer is relevant because such characteristics will push the consumer to try new technologies such as SMT. Thus, we have labeled this construct as *inherent innovativeness*. In addition, as SMT comes with additional costs, interviewees noted *willingness to pay* as being salient.

Conceptual Model

In developing our contextualized model, we took a three-layered approach: (1) use of the PLOC framework as the foundational theory to understand the primary variables that would affect SMT adoption, (2) use of qualitative data to identify the specific SMT context-based constructs that have an effect, and (3) use of the qualitative data and micro-level theories, where relevant, in addition to the literature on PLOC to develop and justify the hypotheses.

We rely on intention as the dependent variable because "intention is the most proximal influence on behavior and mediates the effect of other determinants on behavior" (Venkatesh and Brown 2001, p. 76). Intention is the subjective probability that a person will perform a certain behavior. Individual intention is predicted by attitude, the perceived locus of causality (PLOC), and the SMT-specific variables. We define the salient constructs in Table 1.

Technology adoption researchers have repeatedly argued for the role of individual attitudes on intention to adopt household technologies (e.g., Brown and Venkatesh 2005; Venkatesh and Brown 2001). In other words, researchers have specifically claimed that "all else being equal, people form intentions to perform behaviors toward which they have positive affect" (Davis et al. 1989, p. 986). We expect a similar effect for SMT.

Table 1. Constructs and Their Definitions

Construct	Definition
Intention to adopt SMT (Fishbein and Ajzen 1975)	The subjective probability that a person will perform the behavior of adopting SMT.
Attitude toward SMT (Fishbein and Ajzen 1975)	The affective or evaluative judgment of the consumer toward SMT.
Internal PLOC (Malhotra et al. 2008)	Feelings of volition where consumers perceive themselves as the "origin" of their behavior.
External PLOC (Malhotra et al. 2008)	Perceived reasons for one's behavior that are attributed to external authority or compliance. This assumes that no conflict exists between perceived external influences and personal values of the user.
Introjected PLOC (Malhotra et al. 2008)	Theorized to be caused by misalignment of perceived social influences and personal values. Such motivation are related to affective feelings of guilt and shame and esteem-based pressures to act on one hand, and feelings of the self being autonomous on the other. It is often associated with strong self-imposed feelings of coercion that might lead to rejection of the "imposed" behavior.
Perceived privacy risk (Featherman and Pavlou 2003)	Refers to the potential loss of control over personal information, such as when information about one is used without one's knowledge or permission.
Age	The age of the consumers.
Education	The level of formal education of the consumers.
Income	The average income of the consumers.
Household size	The number of people living in the consumer household.
Inherent innovativeness	The extent to which consumers have curiosity and/or interest in innovations.
Willingness to pay for energy efficient innovations	The extent to which consumers are willing to pay for new energy-related innovations.
Annual electricity consumption	The average annual electricity consumed by the household.
Electricity costs per month	The average electricity costs per month.
Extent to which consumers have switched electricity providers	The number of times consumers have switched electricity providers or companies.

H1: *Attitude toward SMT will positively influence consumers' intention to use SMT.*

Internal PLOC is depicted by the intrinsic and the identified PLOC. Both states are characterized by feelings of volition. Intrinsic PLOC refers to behavior that is spontaneous and performed for inherent fun, whereas identified PLOC refers to behavior based on personal values and goals and outcomes (Ryan and Connell 1989). In the case of SMT, users may adopt it if they have the ability to master it (intrinsic drivers) or may be driven by internalized values such as the protection of the environment. For example, one of our interviewees (R21) argued that "ecological awareness in Germany is so big that people would be participating [that is, in adopting smart meters] in large numbers." He/she went on to state that if people are able to see that SMT can benefit the entire society, customers will be more likely to be positively disposed toward it. Such a feeling has been echoed in the literature in the context of green energy (Zarnikau 2003).

H2: *Internal PLOC positively influences the intention to adopt SMT.*

External PLOC refers to perceived reasons for one's behavior that are attributed to external authority or compliance (Ryan and Connell 1989). It represents the least autonomous form of extrinsic motivation and assumes that no conflict exists between the perceived external influences and personal values of the user. The result is a behavior that is typically performed to satisfy external demands. In the case of SMT, such external demands could ensue from recommendations by public institutions or through offering financial incentives. Interviewee R21 mentioned that "[there] should be certain, small financial gain." Similarly, interviewee R20 mentioned that "[as long as] I am saving … money … I have a good feeling [and will be intending to adopt it]."

H3 *External PLOC positively influences the intention to adopt SMT.*

Introjected PLOC reflects less autonomy than internal PLOC but more autonomy than the external PLOC. It refers to internal beliefs of shame and guilt that may arise in individuals, prompting them to behave in a particular way (e.g., Ryan and Deci 2000). Introjected PLOC typically arouses tension and confusion in an individual because it stems from misalignment between an individual's beliefs surrounding a particular behavior and his/her self-perceived autonomy (Ryan and Connell 1989). Because the diversity of interpersonal influence is greater in private settings and adoption is voluntary, the impact of introjected PLOC on technology adoption may be stronger in homes than in workplace contexts. An important aspect of green technologies is that performing ecofriendly behaviors often means conforming to one's surroundings (Bamberg 2003). If individuals experience substantial pressure to be environmentally conscious and perceive that energy suppliers are exerting pressure to use SMT but, at the same time, consider themselves to be autonomous beings, the resulting confusion is likely to negatively influence their intentions to adopt SMT (e.g., Frederiks et al. 2015).

> H4: *Introjected PLOC will negatively influence intentions to adopt SMT.*

Our qualitative study highlighted the effect of several SMT-related factors on adoption. Our earlier suggestion that the household demographic characteristics of income level, household size, age, and education level are important variables in SMT adoption is also supported by the literature. Higher income gives individuals the opportunity to focus on less immediate needs and therefore the possibility to act in environmentally conscious ways—here, adoption of SMTs (Gatersleben et al. 2002; Poortinga et al. 2004). Further, a positive correlation exists between household size and home energy use (Gatersleben et al. 2002; Poortinga et al. 2004). Given that larger households tend to have higher energy usage, such households are always on the lookout for more cost- and energy-efficient options (e.g., Gatersleben et al. 2002). Hence, in such contexts, any energy-saving option, such as SMT, could be more attractive (Mills and Schleich 2010). Our interviewees suggested a similar effect (see Appendix F), with R9 stating:

> In any case the household size influences the probability of the adoption of a smart meter. One has to say clearly that a single household has of course less potential to optimize its electricity consumption compared to a family with four persons.

Brown and Venkatesh (2005) suggest that the age of the household members, especially the head, affects household technology adoption. Older household heads tend to be less aware of state-of-the-art technologies and thus less inclined to adopt such innovations (Mills and Schleich 2010). In our discussions with experts from the energy supplier, we often heard that customers need to be flexible in changing their lifestyle and consumption behavior to adapt to the new tariffs and possibilities offered by SMT, and such flexibility typically comes from younger, more affluent consumers. Attitudes toward environment friendly practices, such as adoption of SMT, are positively related to education because higher education reduces the costs associated with information acquisition and thus consumers with higher education more easily understand new technologies (Mills and Schleich 2010, 2012; Shih and Venkatesh 2004).

> H5a: *Income will positively influence the intention to adopt SMT.*
>
> H5b: *Household size will positively influence the intention to adopt SMT.*
>
> H5c: *Age will negatively influence the intention to adopt SMT.*
>
> H5d: *Education will positively influence intention to adopt SMT.*

Among the energy consumption-related factors, participants frequently viewed average monthly electricity consumption as an important factor. SMT offers the possibility of a significant reduction in energy consumption and thus those with a high average consumption are more likely to adopt SMT. R19 mentioned:

> Our electricity consumption [as a household] was in the area of 7,000 to 8,000 kilowatt hours per year [about three times higher than the average of a German household] …. We have a fully air-conditioned house …. Then I received a smart meter with application software which is installed also locally on our family PC … with this I was able to see the current consumption data afterwards and then also display it on the PC. That information I also used to research the current consumption and then to motivate my family to save electricity by looking after small things like switching off the light after you. I did this by monitoring my monthly consumptions and ran them also into Excel-based evaluations.

Two other variables emerged as important in adoption. For example, R3, among others, pointed toward average electricity costs as having some relationship with household size, saying "especially customers with above average electricity costs will be interested in the new meters." R16 alluded to the switching behavior of consumers with respect to electricity providers:

> Why do customers switch the energy provider? Mainly because of the costs again. So if the smart meter leads to saved costs, I believe there will be a correlation between the switching behavior of a customer and the smart meter adoption.

Below, we list the hypotheses related to the electricity consumption-related variables.

H6a: *Average electricity costs per months will positively influence the intention to adopt SMT.*

H6b: *Annual electricity consumption will positively influence the intention to adopt SMT.*

H6c: *The extent to which customers switch electricity suppliers will positively influence the intention to adopt SMT.*

Another category of variables that emerged as potentially important was perceptions of privacy and risk. Perceived privacy risk refers to the potential loss of control over personal information, such as when one's information is used without one's knowledge or permission (Featherman and Pavlou 2003). Concerns about privacy risk may evoke consumers' skepticism about using SMT and may negatively affect intention to adopt. Privacy risk is also related to consumers' anxiety regarding energy suppliers' abuse of their private consumption data (Beckel et al. 2014). Our interviewees also highlighted this issue. Consumers are often concerned that "smart meters might be used to reveal certain activities that occur within a dwelling—activities that people generally expect to be private" (McKenna et al. 2012, p. 808). Further, consumers often fear "undesired uses" of their smart meter or electricity consumption data, leading to lower levels of adoption (Beckel et al. 2014, p. 409).

H7: *Perceived privacy risk will negatively influence the intention to adopt SMT.*

Interviewees also noted the inherent innovativeness of the consumers as affecting SMT adoption. As interviewee R20 observed about his/her SMT adoption: "The key reason was the desire for something new or the interest to see something new." Studies on environmental friendly products have concluded that residential consumers who "possess innate innovativeness may have an automatic predisposition to prefer novelty," thereby being more open to new technologies (Bhate and Lawler 1997, p. 3). Similarly, "consumers being innovative means being experimental and having an inclination to try different things" and thereby adopt new technologies such as SMT (Shih and Venkatesh 2004, p. 62).

Finally, like any innovative device, SMT is more expensive than a regular metering device. Consumers willing to adopt the new technology therefore must be willing to pay for such innovations. R9 offers a corroborative view:

> I believe that there is a certain segment of the society whom one can convince of paying for a smart metering device based on environmental protection topics. That is if it can be shown to these customers when exactly green energy can be consumed and when it is energy from nuclear or coal plants. That is a customer group which I believe can be reached.

Research on consumer-level technology adoption, such as mobile payments, mobile commerce, and wireless financial services, has found that customers' willingness to pay for a particular service or technology has a strong effect on adoption (Mallat 2007). In addition, studies of environmental friendly products in general, and green power in particular, have found willingness to pay for innovation to be a strong positive factor in technology adoption (Arkesteijn and Oerlemans 2005; Bhate and Lawler 1997).

H8a: *Inherent innovativeness will positively influence the intention to adopt SMT.*

H8b: *Willingness to pay for energy efficienct innovations will positively influence the intention to adopt SMT.*

We present our developed model, the Sustainable Technology Adoption in the Residential Sector (STARS) model, in Figure 2.

Phase 2 Research Methodology

Phase 2 of our mixed-methods design sought to answer the following question: *Does the STARS model explain household adoption of SMT?* Phase 2 employed a survey (administered online in Germany) to test the model. As SMT is still in its infancy in Germany and is not well known to citizens, we briefly illustrated the technology to survey respondents to establish a common technological understanding among all participants. Specifically, the functions of SMT were demonstrated to the participants prior to the start of the survey and

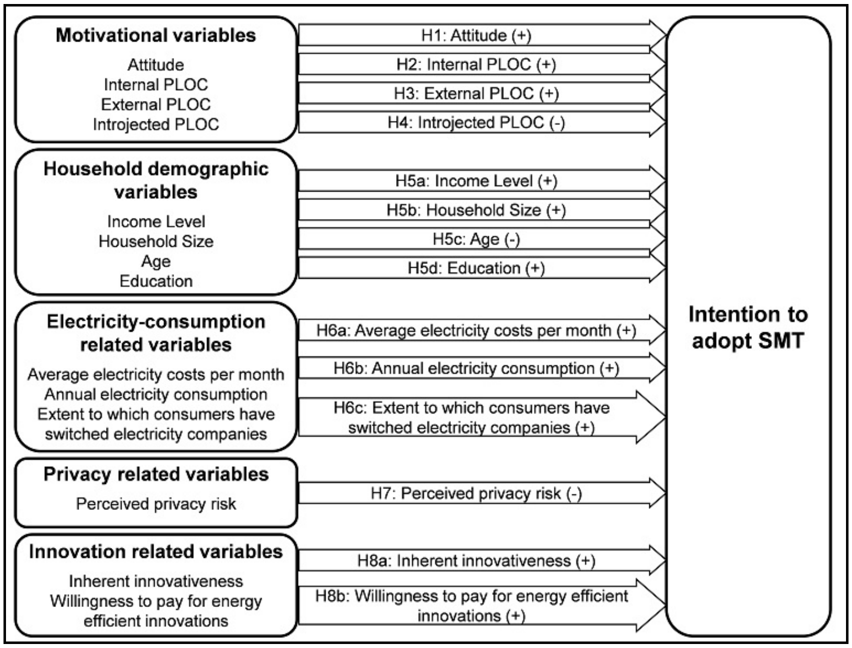

Figure 2. STARS Research Model

one use case surrounding an example dashboard was shown. Use of an online survey had multiple advantages: (1) we could easily add an introduction to SMT, including images, (2) we could discern whether respondents actually read through the introduction or skipped ahead, and (3) we could reach a greater number of citizens to test our model. A leading market research and opinion polling firm in Germany recruited our survey respondents, allowing us to achieve a representative sample of German citizens.

Sample

Our sample consisted of survey respondents in Germany only, which we believe is appropriate for many reasons. SMT is taking on significance in Germany. One important reason for this is the directive set by the European Union (EU) on renewable energy (Council of the European Union and European Parliament 2009). The directive states that, by 2020, 20% of energy mix throughout the EU will need to originate from renewable energy sources. This target has been distributed in various proportions down to the individual member states, with Germany being mandated to include 18% renewable energy in its energy mix. Due to the regional structure of Germany, with its energy-intensive industries and large private consumption peaks in the south of the country, major congestion of the network is expected (Veit et al. 2009). At the same time, stable and non-volatile energy sources, such as nuclear power (by 2022) and coal (by 2038), are being phased out in Germany. Smart meters give the opportunity to steer demand directly by providing a price signal at the demand side, and making devices and humans take environmental friendly, rational, and price sensitive consumption decisions.

Our sampling strategy may be considered "probabilistic" (Venkatesh, Brown, and Sullivan 2016) and our sample consisted of German citizens responsible for energy decisions in their own household. Overall, 3,002 citizens throughout Germany were invited via email to participate in the survey. Incomplete questionnaires and/or those with an implausibly short handling time were removed from the responses. In all, 930 usable questionnaires were analyzed, reflecting a response rate of 31.05%. Participants' age ranged from 16 to 80 years (mean: 49.61 years), with 50.1% (that is, exactly half) being men. We conducted additional analyses that further indicated the representativeness of our sample (see Appendices H and I).

Measures

In measuring intention to use a technology, we used an adapted version of an existing three-item scale (e.g., Brown and Venkatesh 2005; Venkatesh et al. 2003). We measured attitude toward the technology with a four-item scale based on Venkatesh et al. (2003). For PLOC, we used scales suggested by Ryan and Connell (1989) and combined these abstract measures with some self-developed items to create a better fit to the SMT context, resulting in five-item scales for internal PLOC, external PLOC, and introjected PLOC. Finally, we measured specific SMT-related variables such as income, household size, age, education, willingness to pay for energy efficient innovations, average energy consumption, and monthly electricity costs using standard single-item measures and clustered scales provided by the market research firm. Although we drew upon existing literature and the construct of "use innovativeness" in conceptualizing our "inherent innovativeness" variable, we used a single-item measure for this variable, which captures the interest/curiosity of the consumer in new technology (Price and Ridgway 1983). Perceived privacy risk was measured with a seven-item scale adapted from Featherman and Pavlou (2003). We provide details of the items in Appendix J.

Instrument Validation and Pilot Study

We validated our instrument in three steps. First, 16 judges (8 practitioners and 8 researchers) participated in the qualitative pilot study, which consisted of 4 rounds of sorting of the initial questionnaire with subsequent interviews of the judges. This step was especially included to ensure face and content validity (Hardesty and Bearden 2004). After each round, Cohen's Kappa and the inter-rater reliabilities were calculated and a revised questionnaire with 75 items was developed. Second, this set of 75 items was then tested with a small sample (n = 20) to ensure that the mechanics of compiling the questionnaire had been adequate. The participants were also interviewed about the wording and comprehensiveness of the items and their perceptions about the length of the survey once they had completed it. Further, we analyzed the scales by calculating reliability and validity of the measures, and refined the questionnaire accordingly. Finally, in an additional pilot study, we tested the refined questionnaire with a larger sample (n = 110) to further improve it. The computed reliabilities of the scales indicated that the items were appropriate for use in a larger study (Brown and Venkatesh 2005). Further, some of the hypothesized relationships were tested and found to be in the predicted direction.

Analysis

We ensured the quality of our results and the inferences made from the quantitative study by paying close attention to validities (Venkatesh, Brown, and Sullivan 2016). Convergent validity was established by satisfying the following criteria (e.g., MacKenzie et al. 2011): (1) each item loaded significantly on its respective construct (see Appendix K) and none of the items loaded on its construct below the cutoff value of .50[2] (Hulland 1999) and (2) the composite reliabilities and Cronbach's alpha of all constructs were over .70 (see Appendix L). Discriminant validity was established by the Fornell-Larcker test (see Appendix M), which ensured that for each construct, the square root of its AVE exceeded all correlations between that factor and any other construct (Fornell and Larcker 1981; MacKenzie et al. 2011). We also calculated the correlations among the constructs and report them (along with the descriptive statistics) in Table 2.

For the model testing, we conducted a hierarchical regression, with the first block or model including the motivational variables—that is, attitude, external PLOC, internal PLOC, and introjected PLOC—and the second model including all those variables and the SMT-related variables (Miles and Shevlin 2001).

In addition to the model tests, we calculated the tolerance levels and the VIF of each of our constructs. The VIFs of the constructs were not greater than 2.5, with the majority being in the range of 1. Further, the tolerance levels of the constructs were all greater than .10, suggesting that multicollinearity was not an issue in our study.

The results indicated that attitude, external PLOC, and internal PLOC had the predicted positive effect on intention. The effect of introjected PLOC was significant but in the opposite direction. The variance explained by the three PLOC variables and attitude on intention was 57.5% (see Appendix N).

In the second model, the effect of the attitude and motivational variables remained consistent. As Hypothesis 1 predicted, the results indicated that consumers' attitude toward SMT would have a positive influence on the individual's intention to adopt SMT ($\beta = .393$, $p < .05$). Hypothesis 2 predicted that internal PLOC would have a positive influence on the individual's intention to adopt SMT. The results supported this prediction ($\beta = .337$, $p < .05$). Hypothesis 3, which predicted that external PLOC would have a positive influence on individuals' intention to adopt SMT, was also supported ($\beta = .080$, $p < .05$). Hypothesis 4 predicted a nega-

[2] Although many researchers suggest that items should have a loading of .70 or above, others suggest that it is "often common to find that at least several measurement items in an estimated model" have loadings below the .70 threshold and suggest that items with loadings only below.50 should be dropped (Hulland 1999, p. 198).

Table 2. Construct Correlations

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Mean	Std. Dev.
1. Attitude	1															5.58	1.53
2. External PLOC	.55**	1														4.51	1.44
3. Internal PLOC	.68**	.62**	1													4.65	1.56
4. Introjected PLOC	.16**	.37**	.32**	1												2.40	1.30
5. Age	.02	.05	.03	.08*	1											49.60	13.10
6. Education	.04	-.03	-.02	-.07*	-.10**	1										4.13	2.10
7. Income	.01	-.07*	.02	-.07*	.04	.23**	1									4.27	1.39
8. Inherent innovativeness	.11**	.06	.14**	-.01	.00	.04	.07*	1								5.21	1.21
9. Willingness to pay for energy efficient innovations	.03	.09**	.10**	.06	.05	.01	.23**	.13**	1							3.44	.998
10. Average electricity costs per month	-.00	.00	-.00	-.03	.09**	-.08*	.26**	.04	.11**	1						3.87	1.36
11. Annual electricity consumption	-.03	.00	-.01	-.03	.07*	-.00	.28**	.06	.12**	.65**	1					3.59	.984
12. Household size	.02	-.04	.02	-.03	-.28**	.08*	.35**	.00	.08**	.38**	.39**	1				2.39	1.13
13. Extent of switching	-.03	-.03	-.04	-.04	-.11**	.02	.03	.06	.00	-.05	.02	.08*	1			1.91	1.29
14. Perceived privacy risk	-.36**	-.28**	-.38**	-.23**	-.14**	.11**	.00	-.06	-.08*	-.01	.01	.05	.08*	1		4.41	1.31
15. Intention	.69**	.53**	.69**	.25**	-.04	.02	.06	.15**	.07**	-.01	-.00	.04	-.00	-.34**	1	4.64	1.76

**Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

tive influence of introjected PLOC on individuals' intention to adopt SMT. This prediction was not supported, as our findings suggest a positive effect ($\beta = .048$, $p < .05$). In addition, among the different demographic and electricity consumption-related variables, we found that H5a, predicting the effect of income level on intention to adopt SMT ($\beta = .062$, $p < .05$), H5c, predicting the effect of age on intention to adopt ($\beta = -.071$, $p < .05$), H7, predicting the effect of perceived privacy risk on intention to adopt ($\beta = -.043$, $p < .1$), and H8a, predicting the effect of innovativeness on intention to adopt ($\beta = .048$, $p < .05$), were supported. In contrast, H5b, predicting the effect of household size on intention to adopt ($\beta = -.010$, n.s.), and H5d, predicting the effect of education were not supported ($\beta = -.004$, n.s.). Similarly, H6a–c, predicting the effects of average monthly electricity costs on intenton to adopt ($\beta = -.030$, n.s.), average annual electricity consumption on intention to adopt ($\beta = .023$, n.s.), and the extent of switching of energy suppliers on intention to adopt were not supported ($\beta = .019$, n.s.). Finally, individuals' willingness to pay (that is, H7b) was also not found to have the predicted effect on intention to adopt SMT ($\beta = -.003$, n.s.).

The results of the hierarchical regression model suggested that the model with the motivational and SMT-specific variables had a higher R-square (that is, .587 for the motivational and SMT-specific model versus .575 for just the motivational model). Both models were significant, and while the difference in R-square is low (.012), it was significant at $p < .01$, suggesting that the second model is better-performing than the pure motivational model (see Table 3).

Discussion

Our mixed-methods design sought to understand the key variables that affect SMT adoption in households. The results overall indicated support for many of the variables across both strands of our methodology, especially with respect to the role of the different types of motivations and attitude. Specifically, our results highlight that motivation continues to remain a strong predictor of adoption of contemporary technologies, including those facilitating sustainability in private house-

Table 3. Results from the Hierarchical Regression

	Model 1	Model 2
R^2	.575	.587
ΔR^2		.012**
Motivational variables:		
Attitude	.403**	.393**
Internal PLOC	.359**	.337**
External PLOC	.069**	.080**
Introjected PLOC	.042*	.048**
Household demographic variables:		
Income		.062**
Household Size		-.010
Age		-.071**
Education		-.004
Electricity-consumption related variables:		
Average electricity costs per months		-.030
Annual electricity consumption		.023
Number of times switched energy supplier		.019
Privacy related variables:		
Perceived privacy risk		-.043*
Innovation related variables:		
Inherent innovativeness		.048**
Willingness to pay for energy efficient innovations		-.003

*p < .1; **p < .05

holds (e.g., Dholakia 2006; Malhotra et al. 2008). Internal PLOC was more important than external PLOC and is in line with prior work on the effects of external rewards (Dholakia 2006; Melancon et al. 2011). A surprising result was the effect of introjected PLOC. In contrast to our prediction, results showed that tensions arising from introjected PLOC in fact led consumers to be more willing to adopt SMT. A meta-inference from this result is that tensions arising due to more environmental friendly technologies, such as SMT, are likely to move consumers toward the environmental friendly (or "right") way and prompt them to adopt SMT (e.g., Frederiks et al. 2015). We summarize these meta-inferences in Table 4.

In addition, some of the household demographic variables had significant effects and the findings were consistent across both phases of our study. One meta-inference is that SMT adoption is shaped more by *who the consumer is* than *what her/his household is*. In other words, it is more the characteristics of the individual than that of the household in which she/he is situated that affects SMT adoption (e.g., Ottman 1993; Zarnikau 2003). Specifically, individuals who are affluent, young, and more educated (reflecting the idea of the "green consumer") seem to prefer sustainable technologies, over the energy consumption-related criteria.

Although the lack of a significant effect of education is a bit surprising, it echoed some of the past research on both general innovation and smart meters, which experienced similar results, primarily due to a relatively uniform high-level of education in such adopters. Kranz and Picot (2011) found, in their study of smart meters, that respondents in the SMT context tended to be highly educated, a view that was echoed by Ottman (1993) and Zarnikau (2003) in their profiling of the green consumer. Our results confirmed that our sample also consisted of an educated pool, with 70% of our sample having at least an intermediate secondary school leaving certificate in Germany and over 20% of the sample having received university education. It could then be that the uniformity in education and the general level of higher education amongst the respondents resulted in the lack of a significant effect of education.

Another explanation for the lack of effect of some of the variables in the quantitative study (or phase 2 of our study) could be that the majority of our interviewees (in phase 1) worked for energy-related companies, whereas the survey respondents did not. The results reflect discord between what energy providers consider important and what consumers actually prefer. Such a lack of congruence has been well acknowledged for years (Frazier et al. 1977).

Table 4. Development of Qualitative Inferences, Quantitative Inferences, and Meta-Inferences from Our Study (Adapted from Venkatesh, Brown, and Sullivan 2016)

Context and Category of Constructs	Specific Construct	Qualitative Inference	Quantitative Inference	Meta-Inference	Explanation
Consumers' motivation-related	Attitude	Motivation-related variables especially those stemming from financial incentives, social and political pressures, and their own interests in ecology and sustainability affect consumers' adoption of SMT.	Consistent with qualitative findings.	Consumers' motivation, whether stemming from external mandates or from internal feelings of acting in environmental friendly ways positively affects SMT adoption (although internal feelings are stronger). However, in a conflict between external incentives and internal feelings of autonomous individuals, consumers act in more socially altruistic ways, and tend to adopt SMT.	Motivation has consistently been highlighted to be a strong predictor of adoption of a wide range of technologies (e.g., Dholakia 2006; Malhotra et al. 2008). Recent literature in a wide range of disciplines has also argued that when it comes to environmental friendly technologies, the adoption or use is determined more by individuals' feelings of being viewed as doing the "right" thing or being socially altruistic over costs (e.g., Frederiks et al. 2015).
	Internal PLOC		Consistent with qualitative findings.		
	External PLOC		Consistent with qualitative findings.		
	Introjected PLOC		Introjected PLOC was significant but in a direction opposite to qualitative findings.		
Household demographic	Income level	Consumers with higher income are able to spend on environmental friendly devices such as SMT and are more likely to adopt it.	Consistent with qualitative findings.	When it comes to demographic variables, it is more who the consumer is as opposed to what his/her household is that shapes SMT adoption. Consumers with higher income and affordability, younger in age, and more educated are likely to adopt SMT (although education was not significant, it could be a reflection of the fact that this study's sample had mostly higher educated respondents).	Prior research refers to the idea of the "green consumer," who prefer sustainable technologies and are typically, affluent, and young, and more educated (e.g., Ottman 1993; Zarnikau 2003). In the context of some of the demographic variables, the lack of synergy between the qualitative and quantitative findings could hint at also a bit of difference between the respondents in each study. The qualitative study primarily involved respondents who worked for energy companies, while the quantitative study had general consumers. Perceptual differences between providers and consumers have been acknowledged in prior studies (Frazier et al.1977).
	Household size	Consumers in larger households are always looking for more opportunities to save energy and thus more likely to adopt SMT.	Size of the household was not significant.		
	Age	Younger consumers are more likely to adopt SMT.	Consistent with qualitative findings.		
	Education	Consumers with higher education understand newer technologies and more likely to adopt SMT.	Education was not significant.		

Table 4. Development of Qualitative Inferences, Quantitative Inferences, and Meta-Inferences from Our Study (Adapted from Venkatesh, Brown, and Sullivan 2016) (Continued)

Context and Category of Constructs	Specific Construct	Qualitative Inference	Quantitative Inference	Meta-Inference	Explanation
Electricity Consumption-related	Average electricity costs per month	Consumers with higher average monthly electricity costs will be more likely to adopt SMT to reduce those costs.	Electricity consumption-related factors were not found to be directly significant in SMT adoption. That is, average electricity costs per month, annual electricity consumption, or prior switching behaviors did not have direct effects.	Electricity consumption-related variables are mostly associated with consumers' willingness to save costs. Such factors have no direct effects on SMT adoption, except perhaps in contexts where the consumers' household needs (such as their large size) prompt them to be more price-sensitive.	Consumers typically have very little information about their energy consumption. They tend to "find out about their household energy use from meter readings, and even these are not always possible, for example in master-metered apartments" (Steg 2008, p. 4451). Further, such reports usually provide total gas or electricity use, giving little meaningful information on which to base important decisions such as the purchase and installation of smart meters. Consequently, decisions regarding SMT adoption are not often based on deep knowledge of such electricity consumption information, thereby muting the effect of such variables (Steg 2008). Individuals are likely to be more affected by consumption and related costs only under certain contexts such as household size when they focus more on reducing costs.
	Annual Electricity Consumption	Consumers with higher electricity consumption are always looking toward options that help them lower such consumption and thus more likely to adopt SMT.			
	Extent to which consumers have switched electricity companies	Consumers who have a history of frequently switching electricity providers will be more likely to adopt newer technologies such as SMT.			
Privacy-related	Perceived privacy risk	Consumers' concerns about privacy violations will negatively affect their adoption of SMT.	Consistent with qualitative findings.	Privacy violation concerns are important but the so-called privacy calculus (where consumers do a cost/benefit analysis of relinquishing privacy in the interest of enjoying new benefits) is less profound in countries where SMT is a relatively new phenomenon. Consumers in such countries tend to weigh the benefits of SMT more heavily than the concerns of privacy.	The privacy calculus has a strong role in the adoption context of digital and environmental friendly technologies (Xu et al. 2009).
Innovation-related variables	Inherent innovativeness	Consumers who have the desire or interest for novelty or something new are likely to adopt innovative technologies such as SMT.	Consistent with qualitative findings.	Consumers' inherent interests in innovation drives SMT adoption.	Consumers' predisposition to like novelty translates to being more interested in trying new technologies (e.g., Bhate and Lawler 1997).
	Willingness to pay for energy efficient innovations	Consumers who are willing to pay for a new technology are more likely to adopt innovations such as SMT.	Willingness to pay for energy efficient technologies was not found to be significant.	Willingness to pay for energy efficient innovations has no direct effect on SMT adoption.	There is a view that willingness to pay for green power emerges only when consumers have more information on the technology (Zarnikau 2003). As SMT is relatively new in Germany, over time and as consumers learn more, the impact of willingness to pay may become more prominent.

Although our qualitative data suggested the important role of consumers' energy consumption-related factors, the quantitative data failed to support the specific hypotheses. To make sense of this result, we revisited some of our qualitative data and conducted an additional search of the literature. Some of this literature suggests that consumers typically have little information regarding their energy consumption, and they "find out about their household energy use from meter readings, and even these are not always possible, for example in master-metered apartments" (Steg 2008, p. 4451). Thus, decisions are often not based on a deep knowledge of such consumption, muting the effect of such variables (Steg 2008).

An important meta-inference to draw from these results is that energy consumption-related information alone may not be an independent factor affecting SMT adoption and that only in certain contexts do these effects become salient. One such context might be household size, as alluded to by our interviewees:

> If I would live in a large household, I can't expect from everyone to behave energy-conscious. So personally, I think it would be great to automatize as much as possible to save energy without pressuring someone independently. (R11)
>
> A market-driven rollout should first select a useful target group, i.e., large households … with high electricity consumption or households that feed electricity back into the grid, e.g., with solar panels. (R10).

Thus, when it comes to environmental friendly technologies and their adoption, consumer behavior is typically driven by their desire to be viewed as altruistic (e.g., Frederiks et al. 2015). However, different contexts (e.g., household size) often place the focus on consumers and their own family, as opposed to the environment and others, dictating sensitivity to costs and consequently prompting them to adopt SMTs.

The effect of perceived privacy risk was consistent across both the qualitative and quantitative studies. The so-called privacy calculus—that is, the determination of a cost/benefit ratio of relinquishing privacy for benefits—was found to apply in the case of other digital technologies as well (Culnan and Bies 2003; Xu et al. 2009). However, the effects of perceived privacy risk were lower than expected. A meta-inference drawn from this result is that privacy violation concerns are less serious in countries where SMT is a relatively new phenomenon. As SMT is still in its early stages in Germany, people seem to evaluate privacy violation as less important than the possible benefits that SMT can offer.

Inherent innovativeness had a direct effect on intention to adopt SMT (consistent with the qualitative study), with consumers' predisposition to like novelty translating to interest in trying new technologies (Bhate and Lawler 1997). Finally, in contrast to the qualitative study, findings from the quantitative study revealed that willingness to pay for innovation does not have a direct effect on intention to adopt SMT. As time passes and awareness increases and consumers learn more, willingness to pay becomes more prominent. A meta-inference from these results is that with respect to green power, consumers' willingness to pay depends on having more information about the technology (Zarnikau 2003).

Theoretical Contributions

Our study contributes to theory by developing and empirically validating a context-specific model of the adoption of SMT within households. Our model highlights the variables that need to be considered but that have not been examined in prior research. The literature on household technology adoption falls short of providing a relevant set of salient factors that affect SMT adoption. Our study, following guidelines for single-context theory contextualization (see Hong et al. 2014), has extended the literature on household technology adoption by developing a more nuanced model of SMT adoption and by examining a comprehensive set of context-specific factors as antecedents to the intention to adopt SMT. It is important to note that the technology adoption literature, especially in household contexts, has acknowledged the importance of demographic variables but has given them little attention (Venkatesh et al. 2003; Venkatesh et al. 2012). Importantly, we develop a theory-driven, data-grounded model that includes a fairly robust set of demographic and electricity consumption-related variables.

Apart from the work of Malhotra et al. (2008), prior literature on technology adoption has largely relied on the dichotomous concept of motivation (i.e., intrinsic and extrinsic). In contrast, we provide a more refined understanding of user motivations by disentangling the "collections of motivations" influencing users. Rather than applying the extrinsic–intrinsic dichotomy that treats extrinsic motivation in terms of external rewards and intrinsic motivation as being self-inherent, we show that users internalize (identified) social values, such as environmentalism, that in turn can influence behavior as powerfully as intrinsic motivation.

Finally, the results surrounding introjected PLOC offer an important revision to the motivational models of the past by highlighting that context plays a very important role. Specifically, in the context of sustainable technology adoption, despite the inherent dialectic tensions that may arise, consumers tend to display the right behavior, which is the adoption of such technologies. In summary, our model applied an endogenous point of view that fosters understanding of how users perceive their own reasons for acting and the relationship of such reasons to self-perceived feelings of autonomy. The model helps to clearly discern whether the user's behavior results from perceived volition or perceived external influences.

Practical Contributions

The liberalization of energy markets and the transition to more renewable energy systems have brought significant changes to the energy sector, allowing SMT to be a technology that can act as a game changer. The key question is how to leverage the technology and encourage passive energy consumers to use SMT. Our work demonstrated the substantial direct positive effect of internal PLOC. Users who feel volitional about adopting SMT are more likely to adopt it. Thus, providers of SMT must first understand which types of motivations are important to their target groups and then carefully align their marketing activities. Our study's results indicate that energy suppliers have to find a way to offer both internal and external incentives because consumers tend to be motivated by both of these types of rewards. Reaching the mainstream customer would require providing meaningful extrinsic motivations that complement the intrinsic motivations and users' feelings of autonomy and volition. This complementarity is especially important for the services offered with SMT, as the legal mandates surrounding SMT in many countries may arouse perceptions of coercion.

Our identified household demographic and energy consumption-related factors can help energy providers detect customer clusters (such as those with large household sizes) that they can target in the early phases of their SMT rollout or to whom they can offer additional services. Energy providers have a unique opportunity to foster customer loyalty by engaging identified adopters in smart home packages, thereby opening a permanent path as a service provider. Further, given the results regarding perceived privacy risks, we believe that energy providers should take privacy issues seriously and highlight privacy-enhancing measures in advertising campaigns to overcome possible negative media reaction. In other words, energy providers must ensure that customers trust that private data will not be extracted from the smart meters.

Limitations and Future Research

Our study has some limitations, which we believe creates opportunities for future research. First, this study was conducted in only one country. Although Germany is particularly interesting for the study of sustainable energy (given recent governmental mandates surrounding sustainable energy), to validate our results, future research should account for cultural and regional differences, especially as factors affecting household adoption of technology are subject to strong cultural influences (Hoehle et al. 2015; Zhang and Maruping 2008). For example, the German sample could reflect a stronger acceptance of SMT owing to certain strong social values such as environmentalism. Second, although the study is based on a large, statistically representative sample, user perceptions may change over time because of changing societal values or contemporary incidents. Research on the lifecycle effects of household adoption of technologies suggests the need for longitudinal studies in this area (Brown and Venkatesh 2005). Thus, we encourage future research to employ longitudinal studies to get further insights into users' adoption intentions in this sector. Given the effects we found related to variables such as age, income, household size, education, innovativeness, privacy, and electricity use, a longitudinal examination can provide insights into the impacts of changes in the green consumer and/or her/his household situation on SMT adoption.

Conclusion

At a time when new household technologies, such as SMTs, are increasingly being installed in homes, their adoption is facing significant challenges. These challenges are often due to the complex nature of such technologies, which are layered, consisting of a unique combination of a tangible product and innovative services (implemented through different applications), and having the potential to provide information about energy usage. Through a mixed-methods design, and by developing a contextualized model of SMT adoption, our research provides strong evidence that different types of motivation and characteristics of the green consumer, affect the adoption of sustainable household technologies. We believe that the study offers a starting point for further research on this topic and hope that it will help continue the journey into understanding household technology adoption.

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RESEARCH ARTICLE

ADOPTION OF SUSTAINABLE TECHNOLOGIES: A MIXED-METHODS STUDY OF GERMAN HOUSEHOLDS[1]

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Appendix A

Review of the Literature on SMIT Adoption

Authors/Paper	Summary	Comments/Gaps
Kranz et al. (2010)	Kranz et al. empirically test a model of smart metering adoption based on the TAM model and extended by the variable subjective control.	Focuses on socio-psychological constructs in the model, self-selected sample based on an online survey that was linked on an e-energy website.
Kranz and Picot (2011)	Kranz and Picot test a model of smart metering adoption based on the TPB extended by the variable "environmental concern."	Generic model without SMT-specific factors; regional (Munich) student sample.
Wati et al. (2011)	The authors test a model of smart metering adoption based on goal framing theory and the norm activation model. The model is then empirically tested.	No technological or smart meter specific constructs in the model. The sample (Korean households) is very small (n = 100) and consists of 98% male participants.
Wunderlich et al. (2012a)	The authors pretest a model of SMT adoption behavior employing variables of technology acceptance and motivational factors.	No smart meter specific constructs. No representative sample.
Wunderlich et al. (2012b)	The authors test a model of SMT usage behavior employing the TAM model extended by motivational factors.	No smart meter specific constructs in the model. Focus on current smart meter users.
Abu et al. (2014)	The authors review the literature on the extended TAM to form a model for smart metering acceptance.	No quantitative or qualitative data employed to test. No final framework suggested.
Wunderlich et al. (2013)	The authors investigate adoption behavior of transformative services by employing an extended TAM model including behavioral and motivational variables.	No smart meter specific constructs. Focus on differences between users and potential users (adopters) of transformative services.
Wunderlich, Kranz, and Veit (2013)	The authors test a model of smart meter adoption focusing on motivational factors and personal values comparing actual users and non-users of SMT	No smart meter specific variables.
Al-Abdulkarim et al. (2014)	The authors test a model of SMT adoption based on the Unified Theory of the Acceptance and Use of Technology, the innovation diffusion theory and acceptance determinants derived from the Dutch smart metering case.	Small (n = 315), non-representative sample. No further information about response rate. Use of secondary data for model that seems arbitrary; no qualitative validation.
Toft et al. (2014)	The authors test a model of smart grid adoption based on an extended version of TAM (with the inclusion of moral norms). The model is empirically tested in three Scandinavian countries and Switzerland.	No smart meter specific constructs in the model. No qualitative data used.
Warkentin et al. (2017)	The authors develop a model of SMT adoption by drawing on existing models of technology adoption and psychological ownership of information. The model is tested through a survey of paid qualtrics panel of homeowners in the United States.	No smart meter specific constructs in the model. Specific focus on privacy-related concerns and shared benefits only.

Appendix B

Literature Review for Household Technology Adoption/Use

Authors	Research Objective and Technology Context	Theoretical Underpinning	Methodology	Key Findings	Comments
Venkatesh and Nicosia (1997)	Use of multi-media and other technologies at home	Household technology adoption is facilitated by the "technological space" and "social space."	N/A	*Household activities, gender, and perceived needs* play a role in technology adoption; household activities have a mutually interactive effect with *configuration of household technologies*, *attitudes toward technology*, etc., which in turn affects the nature and patterns of use.	General set of demographic, attitudinal, and technology-related factors proposed; specific factors related to energy-usage and privacy concerns that are applicable to SMT not studied.
Venkatesh and Brown (2001)	Adoption of personal computers at home	Theory of Planned Behavior	Phone survey of household head/primary decision-maker; data collected in two phases	Adoption is driven by *utilitarian, hedonic, and social outcomes*; non-adopters are influenced by *technology changes and fear of obsolescence*.	General set of attitudinal, and technology-related factors studied; specific factors related to energy use and privacy concerns that are applicable to SMT not studied.
Hoffman et al. (2004)	Indispensability of the internet	Fragmented literature on social capital and technology diffusion	N/A	Indispensability of technology (or routinization of technology) in homes are influenced by *individual-level determinant*s (e.g., personality, demographics, needs), *technology determinants, and socio-cultural determinants* (e.g., education, profession).	General set of demographic, individual, social and technology-related factors proposed; specific factors related to energy use and privacy concerns that are applicable to SMT not studied.
Shih and Venkatesh (2004)	Home computers	User diffusion model	Survey of household heads	Patterns of use of home computers are affected by the *household social context* in which the user operates such as *experience with technology*, *household communication needs, the personal dimensions such as use innovativeness*, the *technological factors such as the characteristics associated with the innovation, and external factors*.	General set of demographic, attitudinal, and technology-related factors proposed; specific factors related to energy use and privacy concerns that are applicable to SMT not studied.
Arkesteijn and Oerlemans (2005)	Adoption of green electricity in Dutch residences	Fragmented set of literature on innovation diffusion	Phone survey of adopters and non-adopters of green electricity in a single city in the Netherlands	Several factors such as *ease of use, willingness to pay, level of trust in green electricity supplier* among others were found to affect adoption.	General set of demographic, attitudinal, and technology-related factors proposed; specific factors, for example, those related to privacy concerns that are applicable to SMT not studied.
Brown and Venkatesh (2005)	Adoption of home PC and extension of the MATH model	Theory of Planned Behavior	Survey of households in the U.S. without PCs	*Attitudinal, social, and perceived control beliefs* affect household PC adoption. Further, these beliefs were found to vary with the life cycle stage.	A comprehensive set of demographic, attitudinal, and technology-related factors proposed; specific factors related to energy use and privacy concerns that are applicable to SMT not studied.

Authors	Research Objective and Technology Context	Theoretical Underpinning	Methodology	Key Findings	Comments
Choudrie and Dwivedi (2005)	Examine the prevalence of research methods used in the area of general technology adoption, especially within household contexts.	Review of existing literature	N/A	Studies on technology adoption within the household context have typically used *survey methods*.	Does not provide a conceptual or empirical model with which to study SMT adoption.
Brown, Venkatesh, and Bala (2006)	Use of PC in households	MATH	Survey of U.S. households	*Utility for children, applications for personal use, utility for work-related use and applications for fun* affect usage of PCs in homes.	General set of demographic, attitudinal, and technology-related factors proposed; specific factors related to energy use and privacy concerns that are applicable to SMT not studied.
Choudrie and Dwivedi (2006)	Adoption of broadband in households	MATH	Survey of households in the London area	*Several relative advantage factors such as faster access, faster download), utilitarian factors such as use of broadband for educational purposes, hedonic factors such as downloading and playing music were found to be enablers of broadband adoption, while costs and lack of satisfaction with current internet packages were found to be the deterrents of broadband adoption; demographic variables had mixed support.*	General set of demographic, attitudinal, and technology-related factors proposed; specific factors related to energy use and privacy concerns that are applicable to SMT not studied.
Brown (2008)	Charting the past, present, and future of household technology adoption, use and impacts	Review of past literature	N/A	Future research on household adoption should examine the *role that digital divides play on adoption of technologies*, and should also examine the adoption of technologies *where fear of risk, privacy loss*, etc. (such as internet) might play a role should be examined.	Does not provide a conceptual model with which to examine SMT adoption, but does highlight the need to examine the adoption of technologies where privacy, etc., could play a role.
Hsieh et al. (2008)	Post-implementation and continued usage of internet via cable television in households	Theory of Planned Behavior	Survey of LaGrange households in Georgia	*Utilitarian outcomes, hedonic outcomes, influence from friends, family, and government, self-efficacy, perceived ease of use, and availability* all affect intention to continue using.	General set of demographic, attitudinal, and technology-related factors proposed; specific factors related to energyuse and privacy concerns that are applicable to SMT not studied.
Venkatesh (2008)	Whether and how contemporary home life is being transformed through the arrival of new digital technologies	Review of existing studies	N/A	Highlights some key issues to the advancement of digital home technologies such as *technology being too complex for most household users*, *lack of incentives from internet providers to push these technologies*, *privacy issues and interface issues*.	Does not provide a conceptual or empirical model with which to examine SMT adoption, though suggests the *importance of focus on privacy concerns for digital technologies.*
Zhang and Maruping (2008)	Examine cultural influences on household adoption of PCs	MATH and Hofstede's cultural variables	N/A	Proposes the *moderating role of all five Hofstede's cultural variables on the factors affecting household adoption* as per the MATH model.	Focus of the study is on cultural influences. General set of demographic, attitudinal, and technology-related factors proposed; specific factors related to energy use and privacy concerns that are applicable to SMT not studied.

Authors	Research Objective and Technology Context	Theoretical Underpinning	Methodology	Key Findings	Comments
Mills and Schleich (2012)	Residential adoption of energy-efficient behaviors and practices	Review of existing literature	Data taken from the Residential Monitoring to Decrease Energy Use and carbon Emissions in Europe Project survey conducted in 11 countries	*Education, age, household composition and other household characteristics*	Focus on the adoption of energy-efficient appliances and light bulbs, and not on any residential adoption of information technologies; general set of household characteristics studied only; specific factors related to energy use were not studied; the authors highlighted that one of the most critical variables, *actual energy consumption*, should be examined in future studies.
Venkatesh et al. (2012)	Use of mobile Internet technology	UTAUT2	Two-stage online survey of 1,512 mobile Internet consumers in Hong Kong; use data collected 4 months after the first survey	*Extension of the UTAUT model by the addition of hedonic motivation, price value, and habit, as well as other moderating effects. Results indicate that these factors produced a substantial improvement in the variance explained in behavioral intention and use.*	Focus of the study was on a general set of factors that affect consumers' adoption of technology; specific factors related to energy use in the household that are applicable to SMT was not studied.
Brown et al. (2015)	PC adoption in homes	MATH models and other theories of technology adoption	Survey of 5400 households in the U.S.	*Comparison of seven different models such as TRA, TPB, MM, MATH; Studied motivation, but intrinsic and extrinsic motivation only; Results indicated that "context-specific" models of household technology adoption "outperforms" other models.*	Focus of the study was on comparing general models of technology adoption with a specific model of technology adoption in the household; specific factors related to energy use and privacy concerns that are applicable to SMT were not studied.

Appendix C

Elaboration of Decision Choice of Mixed-Methods Study (Adapted from Venkatesh et al. 2016)

	Property	Decision Consideration	Other Design Decision(s) Likely to Affect Current Decision	Design Decision and Reference to the Decision Tree
Step 1: decide on the appro-priateness of mixed-methods research	Research questions	Qualitative or quantitative method alone was not adequate for addressing the research question. Thus, we used a mixed-methods research approach.	None	Identify the research questions • We wrote the qualitative and quantitative research questions separately first and a mixed-methods research question second. • The qualitative research question was: "What are the salient factors that determine the household adoption of SMT?" • The quantitative research question was:"Does the STARS model explain household adoption of SMT?" • The mixed-methods research question was: "Are the factors identified in the qualitative study and as captured through the STARS model supported by the results of the quantitative study?" • We wrote the research questions in the question format. • The quantitative research question was based on results from the qualitative research questions, and the mixed-methods research question depended on the results from both the quantitative and qualitative research questions. • The relationships between the questions and the research process were predetermined.
	Purpose of mixed-methods research	The purpose of our mixed-methods design was to help develop hypotheses for empirical testing using the results of the qualitative study given the lack of research on this topic.	Research questions	Developmental purpose and the results from the qualitative strand were used to develop the research model and the hypotheses tested in the quantitative strand.
	Episte-mological perspective	The qualitative and quantitative components of the study used different paradigmatic assumptions.	Research ques-tions, purposes of mixed methods	Multiple paradigm stance.
	Paradigmatic assumptions	The researchers believed in the impor-tance of research questions and embraced various methodological approaches from different worldviews.	Research ques-tions, purposes of mixed methods	Dialectic stance (we used more of the interpretive and grounded-theory per-spective in the qualitative study and then applied a positivist perspective and deductively tested the developed model in the quantitative study).

	Property	Decision Consideration	Other Design Decision(s) Likely to Affect Current Decision	Design Decision and Reference to the Decision Tree
Step 2: develop strategies for mixed-methods research designs	Design investigation strategy	The mixed-methods study was aimed to develop and test a theory.	Research questions, paradigmatic assumptions	• Phase 1: exploratory investigation. • Phase 2: confirmatory investigation.
	Strands/ phases of research	The study involved multiple phases.	Purposes of mixed-methods research	Multistrand design.
	Mixing strategy	The qualitative and quantitative components of the study were mixed at the data-analysis and inferential stages.	Purposes of mixed-methods research, strands/phases of research	Partially mixed methods.
	Time orientation	We started with the qualitative phase, followed by the quantitative phase.	Research questions, strands/ phases of research	Sequential (exploratory) design.
	Priority of methodological approach	The qualitative and quantitative components were not equally important.	Research questions, strands/ phases of research	Dominant-less dominant design with the quantitative study being the more dominant paradigm.
Step 3: develop strategies for collecting and analyzing mixed-methods data	Sampling design strategies	The samples for the quantitative and qualitative components of the study differed, but they came from the same underlying population.	Design investigation strategy, time orientation	Purposive sampling for the qualitative study given limited general knowledge on SMT, probability sampling for the quantitative study.
	Data collection strategies	• Qualitative data collection in phase 1. • Quantitative data collection in phase 2.	Sampling design strategies, time orientation, strands/ phases of research	• Qualitative study: a mix of both closed- and open-ended questioning using a pre-designed interview guideline. • Quantitative study: closed-ended questioning (i.e., traditional survey design).
	Data analysis strategy	• We analyzed the qualitative data not by "transformation" but by *reducing* it to broad categories using a software, ATLAS.Ti • We analyzed the qualitative data first and the quantitative data second.	Time orientation, data collection strategy, strands/ phases of research	Sequential qualitative-quantitative analysis.
Step 4: draw meta-inferences from mixed-methods results	Types of reasoning	In our analysis, we focused on developing and then testing/confirming hypotheses.	Design-investigation strategy	Both inductive and deductive theoretical reasoning.
Step 5: assess the quality of meta-inferences	Inference quality	• The qualitative inferences met the appropriate qualitative standards. • The quantitative inferences met the appropriate quantitative standards. • We assessed the quality of meta-inferences.	Mostly primary design strategies, sampling-design strategies, data-collection strategies, data-analysis strategies, type of reasoning	• We used conventional qualitative and quantitative standards in ensuring the quality of our inferences. • Design and explanatory quality; sample integration; inside-outside legitimation; multiple validities.
Step 6: discuss potential threats and remedies	Inference quality	We discussed all potential threats to inference quality in the form of limitations.	Data-collection strategies, data-analysis strategies	Threats to sample integration; sequential legitimation

Appendix D

Mixed-Methods Approach and Criteria (Adapted from Venkatesh et al. 2013

Quality Aspects	Quality Criteria	Authors' Response to Venkatesh et al. (2013) Guidelines
Purpose of mixed method approach	Development	This study is divided into two phases: (1) qualitative study involving interviews to understand some of the core SMT-specific factors critical to adoption, and (2) a large quantitative survey. The qualitative study was used to identify factors for model development and hypotheses justification, which was subsequently tested in the quantitative study.
	Sequential less-dominant qualitative followed by dominant quantitative investigation	The scope and objectives of the qualitative investigation using a set of interviews with SMT adopted is very limited; it is primarily to support the quantitative investigation.
Design quality	Design adequacy	The study used qualitative interviews along with limited documentary analysis followed by a quantitative survey. This strategy of examining "raw" data from the phenomenon as a "prelude" to the larger quantitative study ensured that the research model tested using the quantitative study was relevant to the phenomenon of interest (Yin 1993). In doing so, it sought to combine the advantages of the two approaches, achieving depth and insight into the phenomenon as well as the breadth of coverage.
		Qualitative • *Selecting suitable interviewees*: The interviewees were either members of the grid operating division of large energy suppliers who were initiating much of the SMT roll-out in Germany, or other individuals who were potential adopters of SMT, and were thus seen as suitable. • *Entering the field with credibility:* The interviews were conducted by the first two authors of the manuscript, one who is professor (a highly respected individual in the German societal hierarchy), and another who is an analyst in a reputed international organization with a Ph.D. (also seen in high respect in the German society). • *Conduct of interviews:* Based on a protocol, but being sensitive to the principles of flexibility, non-direction, specificity, and range (Flick 1998).
	Analytical adequacy	**Qualitative** • Transcription of the relevant and fruitful (and majority) of interviews, that is interview #8-24(Walsham 2006), the use of interview outline (though evolving and customized for different participants), detailed interview notes from interview #s 1-7, and other documents formed part of the qualitative database that was stored in Dropbox. • Relevant factors codes first generated by Atlas.Ti. • Labeling and re-labeling of the relevant concepts by all three authors after the generation of the codes. The process was iterative, and roughly resembled a *constant comparative analysis*, ending when *theoretical saturation* occurred (Glaser and Strauss 1967). • While no notion of inter-rater reliability was used, the identification and selection of the concepts represented a consensus among the three researchers involved in data collection and analysis, implying some form of convergence and/or reliability. • Triangulation of data from the many interviews; comparison of responses, especially across locations and levels. • Illustration of the themes/factors using quotations may further enhance *plausibility* • Given the exploratory nature of the study, which were geared toward discovery by engaging with "raw" data, and the limited scope of the qualitative nature of the study, the notion of *theoretical validity* is not applicable here.

		Quantitative • Justification of the choice of analysis technique (that is, hierarchical regression). • Sample size of 930 to ensure reasonable power. • Professionally collected data, ensuring that bias in sampling of subjects in avoided or at least minimized. Tests were conducted to compare sample with the entire German population to ensure that the patterns seen in age, gender, etc., were similar to the averages and patterns within the German population.
Explanation quality	Qualitative inference	• The constructs identified through the qualitative study were not only plausible, but many of them were seen to be relevant in a large survey of German SMT adopters.
	Quantitative inference	• *Internal validity* concerns were addressed by developing a model that was theoretically robust, reliability of the data collection process and measurements, and appropriate statistical tests. • *Statistical conclusion validity,* considered to be a "special case of internal validity," was ascertained by ensuring construct validity, and appropriate level of significance for tests, and testing for mulicollinearity appropriately. • *External validity* was ascertained to some degree by ensuring that the sample represented the entire German population by comparing the sample with data of German citizens from the Statistisches Bundesamt (www.destatis.de). We summarize these in Table 4.
	Integrative inference	Much of the originality in the study in terms of *specific antecedents of SMT adoption* can be attributed to the qualitative interviews that was conducted in the introductory phase, but offered the researchers an experience-near view of the phenomenon, given that many of the interviewees were members of the grid operating division of a large German energy supplier. Many of the identified factors were significant in the quantitative study. *The R-square of the model was good, and the addition of the SMT variables to a purely motivational model increased the r-square by .012, and the difference in the r-squares between the first and second models was significant. Based on the above, we can say that* we have been able to achieve a reasonable degree of balance between comprehensiveness and parsimony in the model, and hence *integrative efficacy*. The synergy between the qualitative interviews of SMT adopters, followed by survey of the adopters in Germany, the results of which could be understood in light of the qualitative study indicates a satisfactory level of *integrative efficiency* and *integrative efficacy*.

Appendix E

Details of Interviewees

#	Role in the Family	Role in Organization	Potential Adopter?	Current User?	Prior Experience
R1	Household head	Teamlead in the grid operating division, German energy provider	Yes	No	No
R2	Household head	Coordinator Smart Grid, German energy provider	Yes	No	No
R3	Household head	Employee grid operating division, German energy provider	Yes	Yes	Yes
R4	Household head	Employee in the marketing division (smart metering), German energy provider	Yes	Yes	Yes
R5	Household head	Employee in the marketing division (smart metering), German energy provider	Yes	No	No
R6	Household head	Coordinator field study (MeRegio), German energy provider	Yes	No	No
R7	Household head	Employee division corporate development/field studies Smart Grid, German energy provider	Yes	Yes	Yes
R8	Household head	Project manager M&A at utility, German energy provider	Yes	No	Yes
R9	Household head	Head of department smart metering, German energy provider	Yes	No	Yes
R10	Household head	Project Manager, consulting	Yes	No	Yes
R11	Household head	Innovation manager, regional energy provider	Yes	No	Yes
R12	Household head	Head of department electricity grid management, Germany energy provider	Yes	No	Yes
R13	Household head	Head of department smart meter technology, German energy provider	Yes	No	Yes
R14	Household head	Manager on duty smt rollout, German energy provider	Yes	No	Yes
R15	Household head	Manager smt rollout division, German energy provider	Yes	No	Yes
R16	Household head	Department Head Asset Management Net-division, regional energy provider	Yes	No	Yes
R17	Household head	Department Head, Sales and Distribution Strategy, German energy provider	Yes	No	Yes
R18	Household head	Team lead in the area electricity grid management, Germany energy provider	Yes	Yes	Yes
R19	Household head	Employee in the area electricity grid management, German energy provider	Yes	Yes	Yes
R20	Household head	Specialist Smart Grid, German energy provider	Yes	No	Yes
R21	Household head	Political journalist, German public television / Adjunct Professor of Mass Media	Yes	No	No
R22	Household head	Consultant in the area digital, consulting	Yes	No	No
R23	Household head	Consultant in the area retail, consulting	Yes	No	No
R24	Household head	Principal in the area Energy and Utilities, consulting	Yes	No	Yes

Appendix F

Emergent Themes/Quotes by Respondents

Higher Level Category of Variables	Emergent Themes/ Variables	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18	R19	R20	R21	R22	R23	R24
Attitude	Attitude	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PLOC	Ecological interest		X	X		X	X	X	X	X	X	X			X	X	X		X	X		X			X
PLOC	Love to tinker around with new technologies/services	X		X	X				X	X	X	X		X	X	X	X	X			X			X	
PLOC	Creation of financial incentives and rewards for adoption	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PLOC	SMT as enabling technology	X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
PLOC	Sustainability of financial incentives						X			X					X				X	X	X	X	X	X	
PLOC	Cost/ benefit expectations on financial incentives	X							X		X	X												X	
PLOC	Social pressure based on public opinion	X	X					X		X						X	X	X							
PLOC	Political pressure					X	X		X	X														X	X
Household demographics	Income level		X						X		X		X	X	X	X	X								X
Household demo-graphics	Household size		X	X	X		X					X			X		X							X	X
Household demo-graphics	Age	X		X	X	X					X	X		X	X	X									X
Household demo-graphics	Level of education		X		X				X					X	X	X	X							X	X
Electricity consumption-related characteristics	Electricity costs			X	X	X	X								X								X	X	
Inherent innovativeness	Interest in new innovations	X			X			X	X		X				X	X			X				X	X	
Electricity consumption-related characteristics	Willingness to pay for energy efficient innovations	X	X	X	X	X			X	X	X	X		X	X	X	X	X		X	X	X			X

Electricity consumption-related characteristics	Switching behavior			X												X	X								
Electricity consumption-related characteristics	Electricity consumption	X			X	X	X		X		X					X			X	X					
Electricity consumption-related characteristics	Perceived privacy risks	X	X	X		X		X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
Electricity consumption-related characteristics	Consumption-related factors	X		X	X	X				X		X					X		X			X		X	X

Appendix G

Selected Quotes Substantiating the Different Themes

Subcategory	Selected Quotes on First Order Codes (Open Codes)
Attitude	"Currently I am not using SMT, but I would definitely be interested in using it." (R22) "For me it is more like a nice gimmick that could help me a bit. However, I think nobody really needs it." (R9) "Right now SMT rather has a negative touch for me." (R14)
Ecological interest	"Factors such as an ecological awareness, the willingness to save the environment, are much more important." R8) "I think it would be great if I could say that if I used SMT electricity is getting a bit greener again." (R11) "To enable someone to participate in shaping the energy transition from home, this is how you address people with eco affinity." (R14)
Love to tinker around with new technologies/ services	"Well, if I get any fun out of the money that I spend, it will definitely positively influence my decision. I just love tinkering around and exploring possibilities." (R15) "The key reason was the desire for something new or the interest, to see something new." (R20)
Creation of financial incentives and rewards for adoption	"In the end you need to offer me some monetary benefits." (R9) "… when I get such a technology and have to commit myself to something, changing my habits or just providing data, then I want to get a monetary benefit out of that." (R15) "Out of the three reasons why I would use SMT, the monetary incentive is the most important one for me." (R23) "I would love to see more differentiated tariffs based on the new meters. In the end I want to save some money when I adapt my behavior." (R20)
SMT as enabling technology	"… I can imagine SMT as an enabling technology for the whole internet of things. In the end it all needs to come together and work together and I want to be a part of that." (R22) "I think that SMT and the whole smart home universe need to be tightly interwoven to actually maximize usability. In the end smart home and the comfort effect is what would drive me to get SMT." (R23)
Sustainability of effects/ financial incentives	"In the beginning I will check my electricity consumption but after a while I optimized it and what will happen then? Are these effects sustainable? Will they continue developing an app or something or will I just stop using it?" (R22) "Initially I used it very regularly—that is the first year or something. And then it became slowly less and I have to say; now I actually no longer look on it which reduces my benefits as well." (R18)
Cost/ benefit expectations on financial incentives	"If it would be cost neutral, then I would choose to use SMT in any case." (R8) "The standard user and that is the majority of households will not see any immediate effects on either cost or benefit side." (R10)
Social pressure based on public opinion	"There are a lot of influencing factors that determine the intention of a potential customer…. and in today's society that can be either that you want to save the environment or that social pressure that you have to save the environment." (R17)
Political pressure	"I think that if society believes that SMT is a useful instrument to enforce their environmental policy, then you have to accept that." (R8) "And on the other side you have some politicians and they decide we need SMT. And in the end you have to use it and someone has to pay the bills." (R9)

Subcategory	Selected Quotes on First Order Codes (Open Codes)
Income level	"… the question of the age as well as income level and education are important points in adoption.… And it is clear that a household of 7-8.000 EUR net income per month can more easily carry the additional costs of 70 EUR per year than others who earn less." (R13) "I think a student in his first apartment won't really care about such things as he has other needs like having enough money to get drunk on a party. But later on with a higher income you have the money and you start thinking about the big picture…. Everyone thinks yes we need to reduce energy consumptions… At least it's like this for me and my friends." (R24) "Due to the higher fix costs we think that customers with higher incomes and a higher flexibility in their lifestyles will be more willing to adopt the new meters." (R2) "It will be related to the income although I would not necessarily see it as the dominant factor." (R8) "Well, I think, with increasing household income also the willingness increases." (R16)
Household size	"I think in two cases it does make sense: If it's one commercial unit it's easier to coordinate your consumption patterns and then I think it will scale a bit but not that much. The other case is if you live in a shared apartment because then it's just so much simpler to fairly split the bills which I guess could be very helpful." (R24) " If I would modernize a house and not a small flat—I am currently living in a 70 square meter flat in which I am switching off all consumers by extension plugs with switches—but if I would live in a larger house with more persons, who would maybe not so much have the sense for when to switch off the light, when to lower the radiator, which you also cannot expect from everyone, since everyone has a different affinity to this. Then, if I would live in such a household or in such a flat, then I would indeed try to steer larger [appliances] automatically so to run them automatically. So that these would run when the energy prices are lower or I have e.g. a high electricity production from my photovoltaic installation on the roof. So when generally the energy costs are low in my individual case. Therefore, I, of course, would need smart metering technology for one or the other task." (R11) "In any case the household size influences the probability of the adoption of a smart meter. One has to say clearly that a single household has of course less potential to optimize its electricity consumption compared to a family with four persons."(R14)
Age	"I can imagine that a younger … group, which has a certain techno-budget, that these can imagine to use the smart meter for certain controls and analyses for a certain monitoring and presentation and that they are interested in that." (R10) "… the question of the age as well as income level and education are important points in adoption." (R13) "Young people are always a bit more open towards new technologies compared to more settled people." (R14) "The age plays a role if you say that e.g. you can offer some new features via the smart metering technology, which is interesting for the younger generation like household steering via mobile phone etc. Based on this, the age will play a role." (R15)
Level of education	"I believe that electricity and energy efficiency has a higher weight in societal classes with a higher education compared to less educated classes.… I believe that, a lot in the technology arena and in particular in smart metering which for me is also a technical product, that at the end of the day a lot of decisions are influenced by the education level someone has." (R8)
Electricity costs	"…especially customers with above average electricity costs will be interested in the new meters." (R3) "I see a positive correlation between annual electricity costs of a household and the interest in smart metering technology." (R14)
Inherent Innovativeness	"I believe that a … techno-readiness-group in the customers, who have a certain techno-budget, that these can imagine that they can conduct a certain steering, analyses and monitoring as well a certain presentation of the consumption, that they are interested in smart meter technology." (R10) "I personally would be very interested in monitoring and steering my energy consumption. Maybe only for a few months but right now I would be really interested in doing so." (R22) "Many of the participants seemed to be extraordinarily interested in the technological aspects and the new possibilities offered by the smart meters." (R7) "Technoreadiness, the question of the age as well as income level and education are important points in adoption." (R18) "I think that the groups of people who are technology oriented have a positive attitude towards adopting smart metering technology.… This group will not only have interest in the smart metering technology or the gateway but they are more interested in the utility of this communication connection and that they will be keener on smart home or even more things of this kind." (R15) "As the technology is still in its infancy, the early adopters will probably be especially interested in new technologies and they will probably have a high willingness to pay for them." (R1) "Many of our customers asked how they could use the new technology and which devices could be operated by it automatically and how it will develop in the future." (R4)

Subcategory	Selected Quotes on First Order Codes (Open Codes)
Willingness to pay for energy efficient innovations	"If I had the choice of course, if the smart meter costs 10 Euro more per year than the classical analog meter I would maybe continue to use the analog meter. In my today's life situation this really always depends on what I can effectively do with the smart meter." (R11) "In so far I believe that there is a certain segment of the society whom one can convince of paying for a smart metering device based on environmental protection topics. That is if it can be shown to these customers when exactly green energy can be consumed and when it is energy from nuclear or coal plants. That is a customer group which, I believe can be reached." (R9) "The SMT is strengthening the consumer. This effect can be seen as a savings component, an educational component (in the sense of an ecological rising) and a psychological component, which is that one becomes a protagonist instead of being a passive consumer. Hence, the individual consumer can steer something and is empowered regarding her or his decisions with respect to energy consumption and the impact to the ecosystem. The more expensive electricity is becoming the more important these components are going to be with regard to the consumption decision. Hence, with growing electricity costs, the willingness to pay for a fixed amount to receive SMT is going to rise." (R21)
Switching behavior	"If it is told to households today that in some future they will sometimes have the possibility to save costs using smart meters, this will in most cases not lead to a higher adoption rate right now. But other private customers, who are changing providers frequently, may also see that by adopting the new technology there is a possibility to save money and reduce costs. But that will probably be the group of households who, at this given point in time do not see a big problem in an increase of their electricity bill by 10 EUR per month for buying the smart meter itself." (R15) "Why do customers switch the energy provider? Mainly because of the costs again. So if the smart meter leads to save costs, I believe there will be a correlation between the switching behavior of a customer and the smart meter adoption." (R16)
Electricity consumption	"And I believe that, for example, a smart meter together with applying additional services would maybe be something that might become accepted at the consumer because the consumer realizes that it is helping to reduce the electricity consumption." (R8) "The groups who in the first step will in fact receive intelligent measuring systems [SMT], … these groups are groups with a higher energy consumption. There it is more meaningful to monitor those and then to offer them also the possibilities to steer their energy consumption better." (R10) "It has already proven itself well and it is really very helpful. We definitely used to have an above average electricity consumption." (R18) "Our electricity consumption [as a household] was in the area of 7,000 to 8,000 kilowatt hours per year [about three times higher than the average of a German household]. … We have a fully air-conditioned house [which only have very few German households].… Then I received a smart meter with application software which is installed also locally on our family PC … with this I was able to see the current consumption data afterwards and then also display it on the PC. That information I also used to research the current consumption and then to motivate my family to save electricity by looking after small things like switching off the light after you. I did this by monitoring my monthly consumptions and ran them also into excel-based evaluations … I even incentivized my children and gave them the amount of money which they saved in the electricity consumption at the end of the month on top of their pocket money." (R19)
Perceived privacy risks	"I think knowing what exactly you are using is great … but e.g. my wife sometimes had the feeling to be observed." (R18) "Standards have to be set in a way that hackers don't have the possibility to shut down apartments or to access the consumption data." (R18) "Data protection, especially in regard to taking control over some of my devices, is the only real concern that I have." (R22) "In my opinion the mass of transferred data to the supplier is critical." (R20) "Privacy concerns have to be taken seriously and have to be dealt with actively. It is a topic where I have to say that we as a company decided to actively deal with it and take it up explicitly with our customers. We cannot put this under the carpet since we believe that this will be an important point in the adoption behavior." (R14)
Consumption-related factors	"… a smart meter is reaching out to the customers who would like to simply have transparency regarding their consumption behavior." (R16) "Seeing how much electricity is consumed per room and per device would be very interesting for me. Overall having transparency on my electricity consumption would help me a lot." (R23)

Appendix H

Distribution of Sample and German Citizens

Dimension	Subgroup	Distribution		
		Sample		Germany
		Absolute	Share in %	Share in %
Age [in years]	15–25	45	5%	13%
	25–45	310	33%	30%
	45–65	502	54%	34%
	> 65	73	8%	24%
Gender	Male	466	50%	49%
	Female	464	50%	51%
Education	No graduation	8	1%	4%
	Certificate of secondary school	275	30%	37%
	Certificate of polytechnical school (DDR)	52	6%	7%
	General certificate of secondary education/professional	234	25%	23%
	University-entrance diploma/university degree	333	36%	28%
	Other	28	3%	1%

Appendix I

Distribution of Survey Participants by Federal State

Federal State	In Sample		Germany
	Absolute	Share in %	Share in %
Baden-Württemberg	114	12%	13%
Bavaria	145	16%	15%
Berlin	37	4%	4%
Brandenburg	24	3%	3%
Bremen	7	1%	1%
Hamburg	20	2%	2%
Hesse	65	7%	7%
Mecklenburg-Western Pomerania	18	2%	2%
Lower Saxony	106	11%	10%
North Rhine-Westphalia	212	23%	22%
Rhineland-Palatinate	40	4%	5%
Saarland	7	1%	1%
Saxony	47	5%	5%
Saxony-Anhalt	25	3%	3%
Schleswig-Holstein	38	4%	3%
Thuringia	25	3%	3%

Appendix J

Scale Items for Construct Measures

Attitude:

(1) I assume that it is a good idea to use SMT.
(2) I think, that it is reasonable to use SMT.
(3) All in all, I think it is a bad idea to use SMT.
(4) I like the idea, to use SMT.

Intention:

(1) I can imagine using SMT regularly in my household.
(2) I plan to use SMT in the future.
(3) I intend to use SMT in everyday life.

For PLOC items, each item was preceded by "I use the system …" to capture the self-perceived reasons of behavior.

External PLOC:

(1) … because it is recommended by my energy supplier.
(1) … because it is recommended by governmental institutions.
(3) … because using SMT offers me financial incentives.
(4) … because the European Union recommends using SMT.
(5) … because I can avoid price peaks in peak load times.

Internal PLOC:

Identified PLOC

(1) … because I want to help protecting the environment.
(2) … because I personally like using SMT.
(3) … because I think it is personally important to myself.
(4) … because I want to learn how to use SMT.

Intrinsic PLOC

(1) … because I enjoy using SMT.

Introjected PLOC:

(1) … because I would feel bad if I would not.
(2) … because people who are important to me think that I should use SMT.
(3) … because it is trendy to be green.
(4) … because people who influence my behavior think that I should use SMT.
(5) … because people whose opinions that I value prefer that I use SMT.

Perceived Privacy Risk:

(1) Using SMT could lead to a loss of control over the privacy of my personal data.
(2) Using SMT could lead to a loss of my privacy, because my energy consumption data could be used without my knowledge.
(3) My personal data won't be used for any purposes not related to SMT.
(4) My personal data that is gathered due to the usage of SMT would not be sold to third party providers.
(5) I am concerned about the data security of SMT.
(6) Internet hackers might take control of my payment and consumption data if I would use SMT.
(7) The databases that are used to save my consumption data are protected against unauthorized access.

Net Household Income:

How high is your total monthly net household income? We mean the amount that is a total of salary, wages, income from self-employment, annuity or pension, each after tax and deduction of social security contributions. Please add any income from public aid sources, income from rent, lease, housing benefit, child benefit and other forms of income.

Household Size:
How many persons live in your household, including yourself? Please also think of any children living in your household.

Age:
How old are you?

Average electricity costs per month:
Approximately how high is your monthly payment for electricity?

Inherent Innovativeness:
To what extent do you have an interest in general in technical innovations?

Willingness to pay for energy efficient innovations:
How much are you willing to spend annually on technical innovations, with which you can lower the energy consumption in your household?

Annual Electricity Consumption
How much electricity does your household use each year? For this, please check your last electricity bill (annual bill). The electricity consumption will be stated in kWh (Kilowatt hours). Should the consumption period be more or less one year, please calculate the consumption for one year.

Extent of Switching of Electricity Supplier
Since 1998 consumers in Germany have been given the choice of which electricity supplier they want to use. How is this regulated in your case? How often have you switched electricity supplier since 1998?

Appendix K

Loadings of the Multi-Item Constructs

	Loading	Mean Loading	Standard Error (STERR)	T Statistics	P Values
Intention1	0.911	0.911	0.009	107.066	0.00
Intention2	0.945	0.945	0.005	182.053	0.00
Intention3	0.946	0.946	0.006	168.668	0.00
Attitude1	0.944	0.944	0.007	144.492	0.00
Attitude2	0.943	0.944	0.006	169.645	0.00
Attitude3	0.785	0.784	0.022	36.46	0.00
Attitude4	0.944	0.944	0.006	171.555	0.00
External PLOC1	0.769	0.768	0.018	42.831	0.00
External PLOC2	0.783	0.782	0.018	43.491	0.00
External PLOC3	0.717	0.717	0.024	30.43	0.00
External PLOC4	0.719	0.718	0.025	28.933	0.00
Extenral PLOC5	0.779	0.78	0.016	50.187	0.00
Internal PLOC1	0.816	0.815	0.013	60.48	0.00
Internal PLOC2	0.882	0.883	0.008	105.429	0.00
Internal PLOC3	0.751	0.752	0.019	40.41	0.00
Internal PLOC4	0.785	0.785	0.015	52.449	0.00
Internal PLOC5	0.882	0.882	0.009	97.078	0.00
Introjected PLOC1	0.716	0.715	0.025	28.132	0.00
Introjected PLOC2	0.827	0.825	0.017	49.281	0.00
Introjected PLOC3	0.756	0.754	0.024	31.315	0.00
Introjected PLOC4	0.868	0.868	0.013	65.371	0.00
Introjected PLOC5	0.861	0.861	0.015	57.698	0.00
Perceived Pr. Risk1	0.624	0.62	0.043	14.559	0.00
Perceived Pr. Risk2	0.637	0.634	0.04	16.056	0.00
Perceived Pr. Risk3	0.516	0.513	0.047	11.011	0.00
Perceived Pr. Risk4	0.682	0.682	0.028	24.078	0.00
Perceived Pr. Risk5	0.688	0.683	0.038	18.309	0.00
Perceived Pr. Risk6	0.696	0.697	0.04	17.282	0.00
Perceived Pr. Risk7	0.687	0.688	0.04	17.12	0.00

Appendix L

Reliabilities of Multi-Item Constructs

Construct	Composite Reliability	Cronbach's Alpha
Attitude	.948	.926
Intention	.954	.927
Internal PLOC	.914	.882
External PLOC	.868	.816
Introjected PLOC	.903	.867
Perceived privacy risk	.835	.775
Income	NA	NA
Household size	NA	NA
Age	NA	NA
Education	NA	NA
Avg. elec. costs/month	NA	NA
Avg. elec. comsumption	NA	NA
# of times switched elec. supplier	NA	NA
Inherent innovativeness	NA	NA
WTP for EI	NA	NA

Appendix M

Fornell–Larcker Criterion for Discriminant Validity of Multi-Item Constructs

	EPLOC	IJPLOC	INTPLOC	Intention	PPRISK	Attitude
External PLOC	0.754*					
Introjected PLOC	0.336	0.808				
Internal PLOC	0.660	0.316	0.825			
Intention	0.571	0.250	0.704	0.934		
Perceived priv. risk	-0.293	-0.234	-0.390	-0.345	0.650	
Attitude	0.603	0.162	0.693	0.701	-0.363	0.907

*Diagonal numbers represent the square-root of the AVEs.

Appendix N

Interview Guideline

1. What is the judged gross electricity consumption of your household per annum?
2. Do you use a smart meter—if yes, since when?
3. Can you report on your experience with a smart meter? With what you heard about the usage of smart meters?
4. Which aspects in smart meters do you like? Which don't you like?
5. Which reasons would play a role in deciding for a installing a smart meter?
   a. Which role does your interest in the technology as such play?
   b, Which role do tariff/financially oriented reasons play?
   c. Which role do smart metering services (e.g. consumption control or possibilities of the domain of home automation) play?
   d. Which role do demographic/ innovation-related factors play?
6. Which demands could/can be fulfilled by applying a smart meter?
7. What are your current sorrows with regard to using a smart meter?
8. What are your thoughts on the privacy and data security debate regarding smart meters?
9. How would/do you use a smart meter?
   a. Do you/would you use it regularly?
   b. How did/would your behavior change over the time?
   c. Why did your behavior change?
10. Which role does user friendliness play with regard to this (potential) change in your attitude?
    a. How does user friendliness of the device itself (potentially) influence this change?
    b. Which influence does the quality of the smart metering software interface have?
11. Is there a difference between reasons for continued usage and reasons for initial adoption?
    a. What is/was your perception of smart meters before adoption?
    b. What is your perception adoption of smart meters after adoption (if applies)?
12. How can providers in your opinion improve the devices in a way so that their user experience is improved?
13. What would be a help for you in order to adopt smart metering technologies?
14. What would you do if tomorrow a smart meter would be installed in your home (mandatorily)?

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