# Consumer behavior, social influence, and smart grid implementation

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## Abstract

To achieve the goals of German energy transition especially in renewable energy shares, the smart grid will play a key role in managing the demand able to match more volatile supply and optimizing the entire electricity system. Even though the system transformation is technically feasible, the successful transition cannot live without end users willing to transform their way of using energy. This thesis has explored possible roles of individual consumers in the smart grid implementation and in detail analyzed their influential factors. An online survey was conducted to capture preferences and behaviors of energy consumers during the time period of November 2013 to January 2014. The three roles of private electricity consumers—as consumers consuming electricity through appliances, as citizens holding attitudes towards smart grid applications, and as potential producers of electricity—are targeted. Constructs from the theory of planned behavior were tested by using a sample of 517 German citizens. Structural equation models of individual's electricity saving behavior, their intention to participate in smart grid applications and investment behavior in solar panels were built. It was found that determinants of attitude, perceived norm, and perceived behavioral control together explain 32%-56% of the variance in the three behaviors. Attitude was found to be the most influential factor of individual electricity saving behavior, as well as of citizens' intentions to participate in smart grid applications. For solar panel investment, it is perceived behavioral control that has the highest impact on the behavior.

As the smart grid concept is not well understood by common people, education program and information campaigns are needed, in which social norm marketing is worth more attention, ascribable to the considerable impact caused by the diffusion of norms through social networks. To examine this social influence effect, empirically founded agent-based models for the above-mentioned three behaviors were created to estimate possible behavior changes brought by social norms at the aggregate level. Simulation results show that a reduction of total consumptions by 20% could be achieved in the virtual community due to behavior conformity induced by identified adopters. The potential impact of social norms on home generation and load shift are also promising.

## Zusammenfassung

Für die Umsetzung der Energiewende in Deutschland zur weitgehenden Energieversorgung aus erneuerbaren Energien kommt Smart Grid zur Optimierung des Energiesystems eine hohe Bedeutung zu. Obschon sich die technische Umsetzbarkeit abzeichnet, ist die Verbraucherseite mit den damit verbundenen Verhaltensweisen und dahinterstehenden Einstellungen sehr wichtig für die erfolgreiche Transformation. Diese Arbeit fokussiert auf drei Verhaltensaspekte (Stromsparverhalten, Einstellung gegenüber Implementierung intelligenter Stromnetze sog. „Smart Grid" und Investitionsverhalten in Solarzellen) und deren Determinanten. Eine Online-Erhebung unter 517 Bürgern von November 2013 bis Januar 2014 bildet die Datengrundlage für Strukturgleichungsmodelle zu Verhaltensweisen in Bezug auf intelligente Stromnetze. Theoretisch folgt die Arbeit dem Ansatz der „Theory of Planned Behavior". Es wurde festgestellt, dass Determinanten der Einstellung, sozialer Normen und wahrgenommener Verhaltenskontrolle zusammen 32%-56% der Varianz in den drei Verhaltensweisen erklären. Einstellungen sind der stärkste treibende Faktor für individuelles Stromsparverhalten neben der Absicht der Teilhabe an intelligenten Stromnetzen. Für eine Investition in Solarzellen ist es die wahrgenommene Verhaltenskontrolle, die den höchsten Einfluss auf das Verhalten hat.

Die meisten Menschen verstehen das Konzept hinter intelligenten Stromnetzen nicht gut. Bildungsprogramme und Informationskampagnen sind notwendig: Ein Marketing auf Basis sozialer Normen verdient mehr Aufmerksamkeit aufgrund seines erheblichen Einflusses durch die Diffusion in sozialen Netzwerken. Um die Wirkung dieses sozialen Einfluss zu untersuchen, werden empirisch-fundierte, agentenbasierte Modelle für die drei oben genannten Verhaltensweisen erstellt, um mögliche Verhaltensänderungen durch soziale Normen aggregiert abzuschätzen. Die Simulationsergebnisse zeigen, dass eine Verringerung des Gesamtverbrauchs um 20% erreicht werden kann, aufgrund der Verhaltenskonformität, die durch bestehende Nutzer („identified adopters") etabliert wird. Die möglichen Auswirkungen sozialer Normen auf private Stromerzeugung sowie der Lastverschiebung sind ebenfalls vielversprechend.

# 1. Introduction

Following EU's '20-20-20' agenda, by 2020 renewable energy supply should increase up to 20% of total demand, energy efficiency demands an increase of 20%, and greenhouse gas emissions need to be reduced by 20% relative to 1990 levels. Experts agree that none of the ambitious goals are achievable without a functional smart grid that ultimately optimizes the energy network (Boehme, 2010). Europe's electricity grids have already been too old in fragmented networks, which must be upgraded and modernized to meet increasing demand and possible disruptions. "A smart grid employs innovative products and services together with intelligent monitoring, control, communication, and self-healing technologies" (EU-EG1, 2010, p6). Smart grids can integrate actions of all users connected to it and handle more complexity than today's grid in an efficient and effective way (EU-EG1, 2010). With the integration of information and communication technologies, smart grids will enable two-way exchange of information and power between electricity suppliers and consumers. Smart grids can integrate and distributed intermittent renewable sources such as solar, wind and biomass, and even electric vehicles can be used as batteries to store or release extra energy (Giordano et al, 2011). On one hand, by linking large and small, centralized and dispersed generation sources, smart grids secure a reliable electricity supply able to match real-time demand. On the other hand, to help shape demand to adapt to current supply, price signaling and real-time feedback encourage consumers to control appliances at their homes to use electricity during off-peak time, to save energy, and facilitate domestic generation. Smart grid technology could not only reduce peak loads on utility grids (IBSG, 2008, p2), but also bring great improvement of energy efficiency in the electric transmission and distribution system (Gellings, 2009, p43).

Germany set more ambitious targets than EU agenda: reducing greenhouse gas emissions by 40% by 2020, at least 80% reduction of greenhouse gas emissions by 2050 compared to 1990 levels, and a complete phase-out of nuclear power plants by 2022. Besides, Germany aims to improve the national energy efficiency through a 25%

reduction in electricity consumption by 2050 compared to 2008 levels (Rhein, 2010). By 2050 80% of electricity generated is supposed to come from renewable energy sources, while 80% of electricity is currently from fossil fuels and nuclear energy (BMWi, 2012, p5). The restructuring of the energy system is referred to as energy transition ("Energiewende" in German). To achieve these policy goals, smart grid will play a key role in continuous development of renewables, coordination between electricity production and consumption, and optimizing the whole system. In order to test its integration into the entire supply chain from electricity generation, distribution to consumption, German government initiated E-Energy programme in 2008 and funded 140 million Euro for developments of smart grid technologies and standards. Six model regions were selected to receive funding to carry out research and test a range of smart grid technologies, and develop energy-specific business activities both at the market level and the technical operational level. The pilot projects are: eTelligence (Cuxhaven), E-DeMa (Rhein-Ruhr), MEREGIO (Baden-Württemberg), Model City of Mannheim 'MoMA' Project (Rhein-Neckar), RegModHarz (Harz), and Smart Watts (Aachen) (E-Energy, 2011).

In the smart grid implementation, end consumers, the government, energy companies, and IT companies all have their respective roles. In particular, how could smart grids work without customers? The transformation of energy system changes the role of consumers dramatically by shifting the passive distribution to active involvement (Mengolini and Vasiljevska, 2013, p6). At this early stage, it is important to figure out exact roles of consumers, their opinions, their attitudes, motives and barriers towards relevant technology developments. It helps direct efforts to raise consumers' awareness of active participation in the electric power system and involvement in the new energy service development process to ensure good performance of services (Gangale et al, 2013). European Commission Smart Grid Task Force acknowledged the role and uncertainties linked to consumers' engagement and education as "a key task in the process as there will be fundamental changes to the energy retail market. To deliver the wider goals of energy efficiency and security of supply there will need to be a significant change in the nature of customers' energy consumption (…). A lack of consumer confidence or choice in the new systems will result in a failure to capture all of the potential benefits of Smart Metering Systems and Smart Grids" (EC SGTF, 2010, p5). The level of consumer engagement and how consumers make decisions in the energy market will affect the market development trajectories. Therefore, "understanding what energy customers want and how they behave is fundamental" for the market design (Mengolini and Vasiljevska, 2013, p7). It explains why many pilot projects and field studies target household consumers and investigate the way they use energy. All pilot projects in the German E-Energy programme tested the electricity saving and load shifting potentials of residential consumers. The results show that saving potential for households is available up to 10% and for the load shifting potential is maximum 10% (B.A.U.M., 2012).

As the decentralized mode of operation emerges, the vision of "community grid" is gaining acceptance, that is, "an increasing number of installed renewables are now owned by citizens, farmers and energy cooperatives" (Mengolini and Vasiljevska, 2013, p31). Consumers form communities and produce renewable energy locally, which could be used as a basis for regional coordination of energy supply and demand. Community based social marketing could become part of this development to disseminate norms and increase acceptance of technologies. The thesis focuses on the social norm approach in social marketing, as it is overlooked and worth more attention in the marketing research and practice for electricity use. Social norm marketing campaign can have maximized impacts when using appropriate reference group with which a target group most associates. In addition, effective normative messages may avoid inadvertent increases in socially undesirable behaviors (Burchell et al, 2013). Well-designed marketing strategies can have significant effects on routine behaviors and pro-environmental behavior changes (Mengolini and Vasiljevska, 2013, p32). For energy-related behaviors, we do not know much about the single effect caused by social norms. In pilot projects or field studies, price incentives are sometimes combined with normative messages. Or normative feedback about what other people do or expect are mixed with individual feedback about own historic consumption. To evaluate the usefulness of social norm approach we should know more exactly about behavior changes contributed only by social norms.

In short, the thesis will try to answer the research questions:

1. What are possible roles of households in the smart grid implementation?
2. Which factors influence these different individual behaviors? And to what extent?
3. How much can social norms encourage aggregated behavior changes?

Chapter 2 will start answering the first research question. Information about consumer preferences and influential factors on related behaviors was captured with an online survey. Preliminary results will be described in Chapter 5, which presents the consumer roles as electricity end users, potential participants in smart grid applications and supporters of renewable technologies (particularly photovoltaics). Chapter 3 introduces several theories used often in pro-environmental behaviors and technology acceptance. Constructs from the theory of planned behavior (TPB) were referred to when designing questionnaire items for determinants of energy-related practices. In order to investigate relationships among constructs from TPB, structural equation modelling analyses will be presented in Chapter 6, which will answer the second question. In Chapter 7, agent-based modeling will be used to estimate the effect of social norms as intervention strategy, so as to find out the level of behavior changes through social interactions. For comparison, relevant social influence studies are reviewed in Chapter 4, which also provides theoretical background for the interaction simulation.  Chapter 8 will discuss important findings and limitations of the study before a brief conclusion (Chapter 9).

Figure 1 presents an overview of the research framework of this thesis. After exploring the roles of households in the smart grid implementation (research question 1, Chapter 2 & Section 5.3), electricity saving, consumer participation in smart grid applications, and solar panel investment behaviors will be targeted in later analysis. For most consumers, they have no experience participating in the field tests of smart-grid-related applications, therefore the thesis focuses on their engagement intentions.

Influential factors of these behaviors will be assessed at the individual level to test the constructs in theory of planned behavior (research question 2, Chapter 6). Individual actions can be aggregated into behavioral categories, which cannot be reflected at the individual level. Little communication was found between researchers at these two levels of analysis—the individual level and aggregate level (Fishbein and Ajzen, 2010, p250). The theory of planned behavior provides a useful bridge: On one hand, the theory focuses on determinants of individual behaviors and includes perceived norm to capture normative influence on consumers; On the other, at the aggregate level, based on empirical data of individual preferences, the role of social influence on consumer behaviors embedded in social networks can be further examined in agent-based modeling. As innovative practices' information on their attributes (e.g., costs and benefits) diffuse through interpersonal communications, consumers' conformity to others' behaviors will be combined with their internal antecedents (see Section 7.1 for more descriptions). The dynamic behavioral changes contributed by social norms that diffused in networks (research question 3, Chapter 7) will be then discussed. Examining the strength of social influence in aggregated behavior changes including adoption of new technologies may yield insights for further development of intervention strategies and policy recommendations.

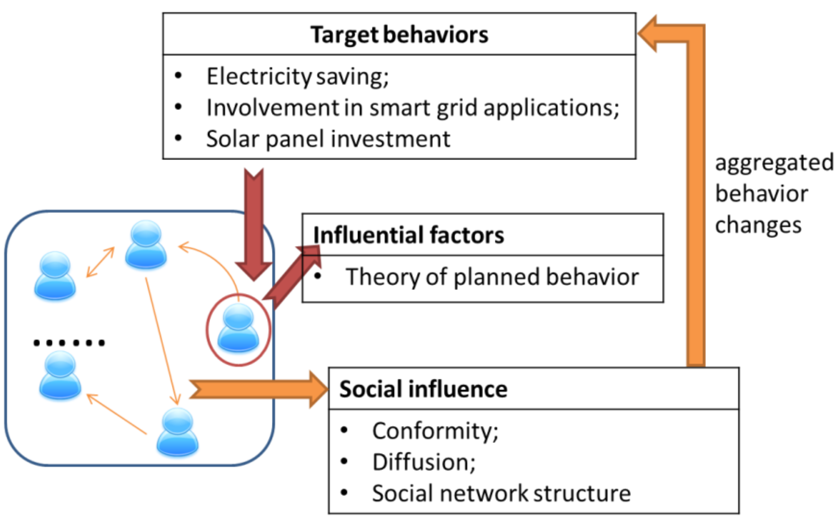



**Figure 1. Research framework: overview of the used concepts**

## 2. Key roles of households in the smart grid implementation

**Research question 1: What are possible roles of households in the smart grid implementation?**

This chapter will explore major roles of households in the smart grid implementation.

In the conventional power grid, households are absolutely passive users and bill payers. In the electricity bill, it is noteworthy that private consumers need to pay for the power cost for supplier, grid charges, renewable energy surcharge (EEG-Umlage) and a surcharge for combined heat and power (CHP) plants (BDEW, 2015). Then the surcharges on electricity bills will be used to support development of renewable energies or CHP plants. For example, renewable energy surcharge pays the feed-in tariff for renewable energy producers.

Unlike the traditional grid, the future smart grid will allow consumers as more active players in the system. Smart grid will make consumers more informed of how they use electricity and encourage them to adjust consumption plans especially during high-cost, heavy-load times. Consumers are expected, together with suppliers, to make the grid operated in a more transparent, interactive and efficient way.

Besides, with the rise of roof photovoltaics, some citizens have a new role: electricity producer and consumer as one—***prosumer***. Smart grid will facilitate the connection and operation of dispersed generation sources better than the old system. Prosumers will be new and important participants in the electricity market.

In the smart grid implementation households could also participate in grid infrastructure planning as citizens, holding attitudes towards certain technologies. Households can be potential owners of smart meter and smart appliances, which are important components of smart grid. Smart meter is an electronic device that records customer consumption in certain time intervals and provides the measurements over a communication network to the collection point (Federal Energy Regulatory Commission, 2008, p5). As a feedback instrument, smart meter can inform households of their real-time consumptions. Smart appliances are appliances designed which can be linked to smart meter and energy management system, possible to be automatically controlled by trigger signals (B.A.U.M., 2012).

The three roles of private electricity consumers—as consumer consuming electricity through appliances, as citizen holding attitudes towards smart grid applications, and as potential producer of electricity (focus on solar panels)—will be more in detail disclosed (see Section 5.3) with an online survey.

# 3. Exploring pro-environmental behaviors and technology acceptance

3.1 presents main theories used to understand pro-environmental behaviors and consumer acceptance of technology. Then come the reasons why the theory of planned behavior (TPB) was chosen to referred to when designing questionnaire items for determinants of target behaviors. The application of TPB constructs will be discussed in Section 5.4.

## 3.1 A glimpse on theories explaining pro-environmental behaviors and technology acceptance

**Theory of reasoned action (TRA) and theory of planned behavior (TPB)**

The theory of reasoned action (Fishbein and Ajzen, 1975) proposed that a person's intention to perform a given behavior is determined by the person's attitude toward the behavior and the person's subjective norm. Intention is identified as the immediate antecedent of performing the corresponding behavior (see Figure 2). The attitude results from the person's beliefs and evaluation of behavioral consequences. Subjective norm refers to the person's normative beliefs and motivation to comply. Normative beliefs are the person's beliefs that important referents think he or she should or should not perform the given behavior. Generally, individuals intend to perform a certain behavior when they evaluate it positively and when they believe important others[1] think they should perform it.

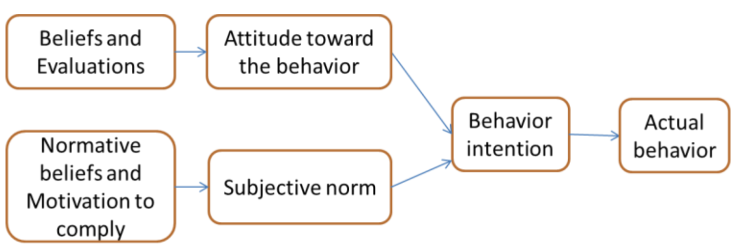



**Figure 2. The theory of reasoned action (TRA) (Fishbein and Ajzen, 1975)**

[1] Important others are individuals whose preferences about a person's behavior are important to him or her.

The theory of planned behavior extended the theory of reasoned action and added a third determinant perceived behavioral control, due to TRA's limitations in dealing with behaviors over which individuals lack full volitional control (Ajzen, 1991). Perceived behavioral control refers to the perceived ease or difficulty of performing the behavior. As shown in Figure 3, TPB suggests attitude, subjective norm and perceived behavioral control jointly predict "intention" with high accuracy. And it assumes that a person's behavioral intention, together with perceived behavioral control, can predict the actual behavior better. Overall, the more favorable the individual's attitude and perceived social pressure concerning the behavior are, and the greater the perceived behavioral control is, the stronger the person intends to perform the given behavior. The stronger the behavior intention is, and the individual has required opportunities and resources, the more likely he or she performs the behavior.

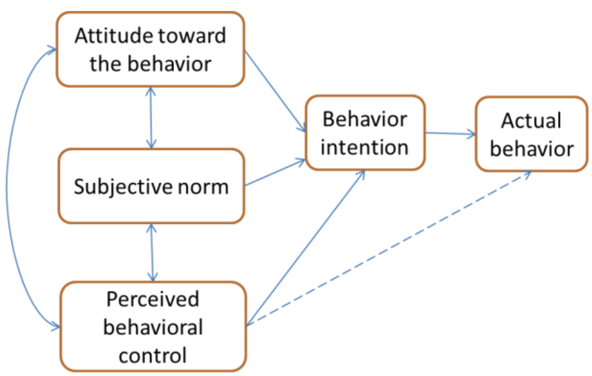



**Figure 3. The theory of planned behavior (TPB) (Ajzen, 1991)**

As subjective norm represents only one source of normative pressure (injunctive norm) that important others think the individual should or should not perform a particular behavior, there is another kind of social pressure that the actions of referents can serve as evidence for compliance with descriptive norms. Therefore, Fishbein (2000) recommends measuring both injunctive and descriptive norms. Fishbein and Ajzen (2010) use the term "perceived norm" to capture the overall normative influence experienced with respect to a given behavior instead of subjective norm for the current framework (p133).

### Technology acceptance model (TAM)

Davis (1989) used TRA as a basis and developed the technology acceptance model (TAM) to explain individual technology acceptance, especially for information system. As shown in Figure 4, TAM proposes that the actual usage of technology can be well predicted by measuring user behavior intention. Besides, TAM suggests behavior intention to use a specific system is determined by user attitude and perceived usefulness. Perceived usefulness and perceived ease of use affect user attitude toward using the system. Perceived usefulness refers to “the degree to which a person believes that using a particular system would enhance his or her job performance” (Davis, 1989, p320). Perceived ease of use refers to “the degree to which a person believes that using a particular system would be free of effort” (Davis, 1989, p320). Perceived usefulness is also influenced by perceived ease of use, which means, the easier the technology is, the more useful it can be. In addition, external factors (e.g., system characteristics, system development process, and user support) may influence perceived usefulness and perceived ease of use. However, Davis et al (1989) and Davis and Venkatesh (1996) found behavior intention to use is not fully mediated by the attitude. User behavior intention could be determined directly by perceived usefulness and perceived ease of use. Therefore, in TAM, the three constructs—behavior intention, perceived usefulness and perceived ease of use—are major determinants for explaining user behavior.

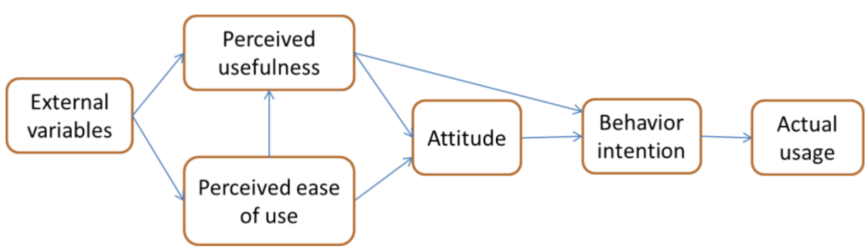



**Figure 4. Technology acceptance model (TAM) (Davis et al, 1989)**

### Diffusion of innovation (DOI) theory

Everett M. Rogers developed the diffusion of innovation theory to explain how an innovation diffuses over time through the members of a social system. As new ideas or products create certain uncertainties about their advantages and disadvantages, the innovation decision process can be individual information-seeking and information-processing activities for uncertainty reduction (Rogers, 1983, p13).

Five stages are identified in the innovation decision process (Rogers, 1983, p20-21):
(1) Knowledge occurs when an individual is exposed to an innovation's existence and gains some understanding of how it functions.
(2) Persuasion occurs when an individual forms a favorable or unfavorable attitude toward the innovation.
(3) Decision occurs when an individual involves in activities that lead to adoption or rejection of the innovation.
(4) Implementation occurs when an individual puts an innovation into use.
(5) Confirmation occurs when an individual seeks reinforcement of an innovation decision already made, or may reverse the previous decision if exposed to conflicting messages about the innovation.

In addition, Rogers (1983, p248-250) classify members of the social system into five ideal adopter categories based on the degree to which an individual is relatively earlier in adoption than other members. **Innovators** are venturesome, quite eager, want to be and are often the first to try new ideas. **Early adopters** are the second fastest individuals to adopt an innovation. They have the highest degree of opinion leadership in the social system, embrace change opportunities and aware of judicious innovation decisions could help maintain central communication position. The **early majority** adopts new ideas just before the average member of the social system and is deliberate decision-maker. The **late majority** is skeptical of change, and adopts new ideas until most others in the social system have tried. **Laggards** are very conservative, suspicious of innovations, resistant to them and are the last to adopt.

### 3.2 Usefulness of theory of planned behavior

The theory of reasoned action (TRA) does not consider volitional control variable and the theory of planned behavior (TPB) added the construct of perceived behavioral control. Technology acceptance model (TAM) adapted TRA and replaced determinants of attitude in TRA by perceived ease of use and perceived usefulness. The importance of attitude toward behavior is often highlighted in empirical studies. Attitude is not only an important predictor but also serves many functions for individuals, such as knowledge function, value-expressive function and utilitarian function (Valente and Schuster, 2002, p113). TAM does not include subjective norm as a determinant of intention as well. Besides, the diffusion of innovation (DOI) theory can be used at the macro level and micro-level to study technology adoption. For the micro-level of individual adoption, it is perceived attributes of the innovation (relative advantage, compatibility, complexity, trialability and observability) that influence adoption rate (Rogers, 1983, p15-16). But this theory works not so well to explain adoption decision when potential adopters lack resources (e.g., money) or access to technologies (Wilson and Dowlatabadi, 2007; Valente and Schuster, 2002, p110). And the proposed innovation decision process seems to represent a linear relationship between knowledge, awareness, intention and behavior (Wilson and Dowlatabadi, 2007, p177). However, it is relatively easy to raise awareness but not improve attitudes. It is beliefs that can turn to attitudes, while awareness might be only important at the beginning of developing beliefs (Valente and Schuster, 2002, p113). Therefore, the questionnaire design is based on the belief-based model TPB with inclusion of important predictors such as attitude, perceived norm and perceived behavioral control.

Ajzen and Fishbein (1977) proposed that attitudes towards objects or actions stem from underlying beliefs concerning the objects or actions. The theory of planned behavior assumes attitudes toward a given behavior result from the person's accessible beliefs about the outcomes of performing the behavior. Not only behavioral beliefs determine attitude toward the behavior, but also normative beliefs concerning the prescriptions and behaviors of important referents produce perceived norm, and control beliefs regarding facilitating or inhibiting factors lead to the perception of the person's ability to carry out the behavior (i.e., perceived behavioral control ) (Fishbein and Ajzen, 2010, pp20-21). Meta-analytic reviews have demonstrated TPB's predictive power in general (Ajzen 1991; Godin and Kok, 1996; Notani, 1998; Armitage and Conner, 2001).

Furthermore, TPB can be widely applied to various behaviors in different contexts, such as pro-environmental behavior and technology adoption. Due to its simplicity, TPB is very easy to understand, frequently used by researchers and well supported by empirical evidence. It has been used in hundreds of studies in recent two decades (Ajzen, 2015). And a variety of studies indicate that TPB provides a solid conceptual framework to help explain individual conservation focused and innovation-adoption behaviors (Bonnes et al, 2003; Weigel et al, 2014). Therefore, TPB was used as the theoretical foundation to design the questionnaire items for electricity saving behavior, intention to participate in smart grid applications, and investment in solar cells. Using the same conceptual framework for the three enables rough comparisons in between. On the other hand, for non-users of innovation like smart grid they might have low level of knowledge and quite vague perceptions of the innovation's characteristics. So questions are about their general attitudes but not focused much on innovation attributes. Some examples that have examined the applicability of TPB in related fields will be presented in the following part. It is very common that energy- and technology-related behaviors apply TPB constructs. In particular, attitudes and perceived behavioral control appear to be leading determinants of individual pro-environmental behavior (Armitage and Conner, 2001; Abrahamse and Steg, 2009) and innovation-adoption behavior (Weigel et al, 2014).

To sum up, TPB is very easy to apply, and could supply general information of opinions about a technology from users and those people who have not used it or even do not know it. Perceived characteristics of the innovation is important as well, although not listed out separately in the applied framework, the questionnaire has integrated them into evaluation questions of the specific technology.

### 3.2.1 TPB applications in environmental conservation

Harland et al (1999) investigated Dutch citizens (N = 305) who participated in a pro-environmental behavioral intervention program through a survey. The survey measured five specific behaviors, which are using unbleached paper, reducing meat consumption, using mass transit, installing energy-saving light bulbs, and turning off the water when brushing teeth. The three constructs (i.e., attitude, subjective norm, and perceived behavioral control) of TPB were found to be significant predictors of intentions for the behaviors. The TPB constructs accounted for 37%-51% of the variance in the intention to perform the five behaviors. Determinants of attitude, subjective norm, and perceived behavioral control together explained 13%-39% of the variance in the past behaviors.

Abrahamse and Steg (2009) described the analysis of an internet-based survey in Gröningen of the Netherlands during the period of October 2002-March 2003. The study examined variables from TPB in relation to household energy use and energy savings but subjective norm was not included. Results indicated that attitudes and perceived behavioral control contributed significantly to explain the variance in direct energy use. The two constructs were also found to be significant determinants of total energy savings and direct energy savings.

Abrahamse and Steg (2011) examined if TPB variables could explain household energy consumption and intentions to reduce the energy use by measuring behavioral antecedents before and after an intervention. They found when other TPB variables were controlled, respondents with more positive attitudes towards energy conservation tended to consume less energy. Attitude, subjective norm, and perceived behavioral control could explain 18% of the variance in the intention to reduce energy use. Perceived behavioral control and attitude toward energy conservation were found positively related to intention to reduce household energy use.

János (2011) conducted an online survey (N = 1582) applying TPB to study university students' intention and behavior in saving energy in Portugal. The results show that attitude toward saving, subjective norm were statistically significant predictors of the intention to save energy. Perceived behavioral control had significant relationship with energy saving behavior but not with intention.

Stokes et al (2012) described that a Rewire project—an innovative energy conservation campaign—used TPB as theoretical framework to design surveys on energy conservation behaviors, in order to analyze barriers to effective pro-environmental programs. Several common energy conservation behaviors were explored, such as turning off lights when leaving a room/common spaces, turning off printers when not using them, and shutting down computers when going to class/leaving the office. The results of a survey in 2005 showed that student respondents reported combinations of forgetfulness, laziness, and inconvenience as barriers of tasks such as turning off computers when not in use. Most barriers were found related to attitudes. In the 2007 office survey, respondents reported more barriers from subjective norms and lack of control over the behavior.

Based on TPB, Geerts (2013) conducted a scenario-based survey to investigate consumers' intention to save energy and the intention to shift load. The regression analysis showed that attitude has a significant effect on the intention to save energy. Subjective norm has a weak influence on the intention to save. And there is no relationship between perceived control and the intention to save. For the intention to shift load, attitude has an important and significant effect on the intention. Subjective norm still has a weak influence on the intention to shift. Perceived control has a significant and medium effect on the intention to shift.

### 3.2.2 TPB applications in IS adoption

Weigel et al (2014) examined antecedents from theory of planned behavior over the past thirty years of information system (IS) research such as computer use, internet use, email use, internet banking, e-learning, online shopping and so on. They found that TPB is often combined with complementary models like the diffusion of innovation model to study adoption of information systems. The meta-analysis of fifty-eight empirical articles they collected in the information system field shows that attitude toward behavior indicated the largest correlation with adoption propensity. Both social norms and perceived behavioral control were found to have medium effects.

TAM (technology acceptance model) was inspired by the theory of reasoned action (TRA) and often used to explain the usage or intention to use a technology. Some studies which applied TAM model measure the construct "attitude toward behavior", but some omit attitude. In the information system research, incorporating factors such as subjective norm, or including self-efficacy as external precursor is one of major modifications of original TAM models (King and He, 2006). Schepers and Wetzels (2007) conducted a meta-analysis of studies using TAM across different settings. They included the subjective norm in the analysis and examined the role of subjective norm. Results indicated that subjective norm has a significant influence on perceived usefulness and behavioral intention to use. Subjective norm influences one's intention to use a technology via the compliance effect, and can also influence technology acceptance through perceived usefulness—the internalization effect—interpreting information from important others as evidence about reality (Venkatesh and Davis, 2000).

Few studies were found which only apply TPB for adoption of smart technologies. More studies use adapted TAM model or diffusion of innovation theory to investigate consumers' perceptions of the innovation characteristics. The following part describes main articles as long as any of the three TPB constructs (attitude, subjective norm, and perceived behavioral control) is involved to explain the adoption of smart technologies like smart meter.

Kranz et al (2010) used an extended TAM model to study the German household acceptance of smart metering technology. They added the construct of subjective control, which is a person's need for control, to capture consumers' concerns about loss of control after installing smart meter, and the resulting negative emotions could influence the acceptance. They conducted an online survey in March 2009. The results indicated that attitude toward use is the most important determinant of the intention to use, and subjective control has medium indirect effects on intention to use through attitude.

Stragier et al (2010) conducted a survey among 500 households in Belgium with regard to their perceptions of smart appliances. TAM model was used as the theoretical foundation to measure the perceptions. The results indicated that both perceived ease of use and perceived usefulness have significant effects on attitude. Attitude has a positive effect on intention to use smart appliances.

Based on TPB and TAM, Kranz and Picot (2012) distributed an online questionnaire among post- and undergraduate students to investigate factors influencing consumers' intention to adopt the smart meter technology. The results show that attitude is the most influential determinant of intention. Besides, intention is also driven by secondary sources' influence (e.g., media) and environmental concerns. But perceived behavioral control has shown non-significant effect on intention.

AlAbdulkarim (2013) integrated innovation attributes of the diffusion of innovation (DOI) theory and the unified theory of acceptance and use of technology (UTAUT) into a hybrid model to investigate consumers' acceptance of a smart meter. The UTAUT model, which is constructed by Venkatesh et al (2003), combines the competence of eight models (i.e., TRA, TAM, TPB, combined TAM and TPB, motivational model, model of PC utilization, DOI, and social cognitive theory). An online survey was conducted between April 2012 and June 2012 in the Netherlands in order to test the hypothesized hybrid model. The results show that performance expectancy proved to be the strongest predictor of consumers' smart meter acceptance. Perceived financial costs and social influence had no significant effects on smart meter acceptance, but were found to be the most important predictors of performance expectancy, and then influence acceptance indirectly. Perceived loss of control was found not among the factors affecting consumers' intention to accept a smart meter.

Toft (2014) conducted an online survey in 2011 in Denmark, Norway and Switzerland to capture private consumers' acceptance of smart grid technology. TAM was employed in the study with the addition of personal norm. The results showed that perceived usefulness and perceived ease of use are significant predictors of the attitude towards smart grid technology in all three countries. Attitude is the most important predictor of smart grid acceptance. Attitude together with personal norm accounts for 63% (Denmark), 78% (Norway) and 64% (Switzerland) of the variance in acceptance of smart grid technology (Toft et al, 2014).

### 3.2.3 TPB applications in home photovoltaics (PV) investment

Many articles have investigated motives and barriers of the diffusion of solar energy in households, which include economic factors (e.g., price, financing), psychological factors especially individual perceptions and environmental concerns, social factors like peer effect, administrative factors (e.g., connection to the grid, institutional support) and technological factors (e.g., feasibility and function-related characteristics) (Jacobsson and Johnson, 2000; Painuly, 2001; Reddy and Painuly, 2004; Dinica, 2006; Faiers et al, 2007; Adachi, 2009; Bollinger and Gillingham, 2012). Some studies use demographic characteristics to understand adopters (Labay and Kinnear, 1981; Sawyer, 1982; Faiers and Neame, 2006).

Some studies use Rogers' innovation attributes (relative advantage, compatibility, complexity, trialability and observability) from the diffusion of innovation theory to investigate households' perceptions towards microgeneration technologies like solar systems (Farhar and Coburn, 2000; Faiers and Neame, 2006; Claudy, 2011). However, few studies were found which only apply TPB constructs to adoption of solar system. Claudy (2011) added subjective norms and subjective knowledge in the survey of green innovation acceptance (e.g., solar water heaters, solar panels) besides of measuring perceptions of microgeneration characteristics. The result showed that home owners who experience strong support (for microgeneration technologies) from important others such as friends and family have a higher willingness to pay for solar water heaters. Home owners who stated that they know someone that operates a solar water heater have a higher willingness to pay as well. But social norms and subjective knowledge have no significant effects on willingness to pay for solar panels or solar water heaters.

### 3.3 The "attitude-behavior gap"

As Eagly and Chaiken (1993, pp155-158) reviewed, criticisms about poor predictability of behavior from attitudes have existed for a long time. From the 1930s empirically weak relations between attitudes and relevant behaviors were suggested (LaPiere, 1934). Later more critics came about weak relations between attitudes and behaviors (Green, 1954; Festinger, 1964; Deutscher, 1966). Critics from Alan Wicker's article (1969) which claimed that attitudes are unrelated or only slightly related to behaviors based on a review of 42 studies attracted a lot of attention. Most of the studies in Wicker's (1969) review were laboratory studies. More survey research maintained that there are moderately strong relations between attitudes and behaviors (Kelman, 1974; Schuman and Johnson, 1976). Hovland (1959) pointed out that the difference depends on whether data were collected by laboratory or survey methods, since situational constraints of laboratory settings could create barriers which discourage the attitude-consistent behavior (Eagly and Chaiken, 1993, p157). Campbell (1963) argued that attitude-behavior inconsistencies are observed more than real (i.e., pseudo-inconsistency) due to ignoring the relative difficulty of behaviors, for example, easy actions in questionnaires but not in a face-to-face situation.

Some scholars sought ways to improve the poor predictability of behavior from attitudes. Fishbein and Ajzen (1974) systematically approached the aggregation problem. They suggested multi-act criteria to assess an attitude measured with an aggregation of attitude-relevant behaviors representative for the domain. The attitude-behavior correlations appeared to be stronger than a behavioral measure consisting of a single behavior (Fishbein and Ajzen, 1974; Eagly and Chaiken, 1993, p159). Ajzen and Fishbein also suggested that high correlations between attitude and behavior can be obtained when the level of specificity of attitudes and behaviors are compatible (Ajzen, 1988). That is to say, specific attitudes toward behaviors tend to be good predictors of specific behaviors. They contended that any behavior has four elements of action, target, context, and time. If the extent of action, target, context, and time elements for both attitude and behavior are assessed at the same level of specificity, attitude-behavior correlations will increase (Eagly and Chaiken, 1993, p163; Fishbein and Ajzen, 2010).

Ajzen and Fishbein tried to address the discrepancy between attitudes and the actual behavior in their theory of reasoned action and the theory of planned behavior (Fishbein and Ajzen, 1975; Ajzen and Fishbein, 1980). The theory of reasoned action introduced the psychological construct “behavioral intention” which mediates relations between attitudes and behavior. Bringing the intention construct into the debate is noteworthy (Eagly and Chaiken, 1993, p168). Then attitude toward the behavior becomes one determinant of intention, and subjective norm also enters the model as the other determinant to consider normative influences, which cannot be neglected since individuals are embedded in social context. In addition, the theory of planned behavior (TPB) can explain behaviors that are not wholly under volitional control, which enlarged the theory of reasoned action. One’s control (over the needed resources, opportunities, and skills) is taken into account as a variable labeled as “perceived behavioral control” in TPB (Eagly and Chaiken, 1993; Kaiser et al, 1999; Fishbein and Ajzen, 2010). In general TPB is supposed to provide better prediction of behavior, which has been also demonstrated by meta-analyses of empirical studies (Ajzen 1991; Godin and Kok, 1996; Notani, 1998; Armitage and Conner, 2001).

In terms of pro-environmental behaviors, positive attitudes toward the behavior may not result in pro-environmental behavior, unless people do believe their efforts can make a difference in combating environmental problems (Roberts, 1996; Gilg et al., 2005; Sütterlin et al, 2011). Subjective norm is also found to affect energy conservation intentions (Thøgersen and Grønhøj, 2010; Sütterlin et al, 2011). A meta-analysis of pro-environmental behavior studies found that pro-environmental attitudes, knowledge about the environmental problem and action strategies are among those many factors that influence pro-environmental behaviors. Situational factors such as economic constraints, social pressures, and opportunities also affect individuals’ actions (Hines et al, 1986-87). These aspects have been considered when constructing questionnaire items based on the TPB framework. The new meta-analysis of pro-environmental behaviors performed by Bamberg and Möser (2007) confirms the behavioral intention mediates the relationships between psycho-social variables (e.g., attitude, social norm, PBC) and pro-environmental behavior. Attitude and PBC as independent predictors of behavioral intention are also confirmed. Reviews of TPB applications (Ajzen, 1991; Armitage and Conner, 2001; Bamberg and Möser, 2007) indicate that social norm sometimes exerts indirect effect on intention via attitude or perceived behavioral control (PBC). These findings are consistent with results of studies in Section 3.2.1. To what extent social norm impacts the intention (or behavior) in a direct or indirect way will be further examined in this thesis.

The gap between pro-environmental attitudes and behaviors is highlighted in studies of reduced energy consumption in the household (Jackson, 2005). To understand environmentally significant behaviors, Stern (2000) divided possible determinants into four major categories: attitudinal factors (e.g., behavior-specific beliefs), personal capabilities (e.g., sociodemographic variables), habits, and contextual factors (e.g., social norms). Abrahamse and Steg (2009) found that energy consumption is determined by sociodemographics (e.g., household size), while energy savings merely correlate with attitudinal factors. Personal norm—the sense of moral obligation to act (Norm Activation Model, Schwartz, 1977)—is often mentioned crucial in pro-social behaviors which is not addressed by TPB. Much work has found that personal norms are significant predictors of behaviors with environmental intent (Thøgersen, 1996; Nordlund and Garvill, 2002; Poortinga et al, 2004; Harland et al, 2007). Value-Belief-Norm theory (Stern et al, 1999) attempted to adjust the Norm Activation model to explain pro-environmental behaviors. In general, TPB appeared to be more powerful in explaining high-cost behavior (Bamberg and Schmidt, 2003), while Value-Belief-Norm theory appeared to be more successful for low-cost behaviors (Gärling et al, 2003; Steg et al, 2005). The influence of personal norms was not studied in this thesis, future research with the addition of personal norms is needed.

Concerning IS (information system) adoption, user attitude is commonly used in individual adoption models that explain information technology usage. Attitude was also found to be a very important determinant of the intention to use smart meter (Kranz et al, 2010; Kranz and Picot, 2012) and smart appliances (Stragier et al, 2010). But it is too early to tell whether control factors influence consumers' intention to use smart products or not due to limited studies. Similar to perceived control, the role of social norm is not clear as well. Therefore investigations in the smart grid environment are meaningful and this thesis contributed one German sample.

## 4. Social influence

Jager (2000, p78) elaborated that the pro-environmental behavior involves individual and social processing: people process information without considering behaviors of others, or people observe behaviors of others as a main information source of determining to perform for oneself. If behavior outcomes are more uncertain, and the more information on others' behavior is available, it will entail more social processing. The characteristics of consumers (e.g., cognitive ability, opinion leadership) will also lead them to different levels of social processing.

In innovation diffusion social influence also matters as information on innovation attributes transmits through social networks (Wilson et al, 2014, p17). Wilson et al (2014) value social influence as one important feature in consumer decision-making, which could influence, constrain or shape decision outcomes.

Social interactions between consumers may result in social spillovers, in which a marketing action that affects one agent then indirectly influences other agents. In the thesis the empirical-based simulation (Chapter 7) will examine this effect of social norms on aggregate changes in adopting a specific behavior within a community—see how powerful the effect is on behavior conformity. Social influence will be explored more deep in this chapter with an explanation of various terms researchers have used in literatures first (Section 4.1). Two types of norms—descriptive norms and injunctive norms—are mostly mentioned in studies related to social influence. Cialdini (2003) stated that both norms can pressure individuals to conform to certain behaviors.

Towards energy practices individual consumers (micro level) have their own beliefs and actions. Understanding internal antecedents of consumer behaviors is an indispensable starting point of engaging individuals in smart grid applications. However, the success of innovation diffusion and optimization of energy efficiency cannot be well judged at the individual level but at the societal level. Individual consumer as the analysis unit is therefore not enough. Consumers are embedded in the social system and belong to different groups such as family and community connected by social networks. The preferences and decisions of an individual can be influenced by the expectations and behaviors of others. Theory of planned behavior does include perceived norm to capture normative influence on the static consumer attitudes, but the aggregate-level outcomes (i.e., adoption rate) brought by social norms were given little explanations (Axsen and Kurani, 2012a). For example, the more individuals adopt new technologies, the chance of related products obtaining attention from other consumers might rise. Besides of market penetration supporters could also facilitate further development of related technologies. And more user-friendly products then attract more consumers. The micro-level behavior of individuals and the macro-level repercussions due to aggregated adoptions mutually affect each other. Macro-level outcomes emerge by actions and interactions of micro units such as individuals (Coleman, 1990). Simple statistical rules of aggregation can be used to link micro actions and macro level properties (Liska, 1990). The thesis pays more attention to the micro-level determinants and the aggregated adoptions of smart grid related practices via social influence mainly from reference groups (interpersonal influence rather than institutional influence).

Axsen and Kurani (2012b) found that among interested households only those who found positive support through interpersonal interactions were willing to shift toward a pro-environmental lifestyle. Intervention studies have discovered that energy conservation can be promoted through information communication through a peer network (Petersen et al, 2007; Peschiera et al, 2010). Peer effects of previous PV installations on the adoption decision of a household have been found by several studies (Jager, 2006; Bollinger and Gillingham, 2012; Müller and Rode, 2013). More detailed review of social influence studies will be described in Sections 4.2 and 4.3. Most field experiments have found that providing consumers with normative information from appropriate reference groups do promote conservation behavior and technology acceptance. IT related research has figured out social influence plays an important part in adoption decisions. Still, the application of social norms engaging consumers in products and practices related to smart grid needs to be explored. Section

4.4 summarizes different perspectives of social influence as theoretical background for the agent-based modeling in Chapter 7.

## 4.1 A glimpse on the terms

**Social norm**

Social norm is one fundamental concept of social psychology. For a long time the influence of social norms has been researched. Being social as nature, people are difficult to resist influence from others. **Social norms** refer to observations of others' behavior and expectations of others for our behavior (Schultz et al, 2008). Others can be family including parents, children and partners, friends, neighbors, coworkers, strangers, and the media. As rules or standards understood by members of a group, social norms can guide and/or constrain individual behavior (Cialdini and Trost, 1998). Many early researches on social norms were about conformity. Deutsch and Gerard (1955) interpreted **conformity** due to two forces—informational influence and normative influence. Normative influence was defined as "influence to conform to the positive expectations of another" and informational influence was defined as "influence to accept information obtained from another as evidence about reality" (Deutsch and Gerard, 1955, p629). The individual is motivated by being liked by group members or by making correct decisions/being accurate in behaviors, which leads to the conformity to a group norm.

**Descriptive norms**

By observing how other people respond to the same situation, it provides information about what is correct especially in an ambiguous or uncertain situation or when the appropriate behavior is unclear. Perceived social support might shape our interpretation of and response to the situation. The reason of following others could be the "social proof" which provides an effective solution and using others' behavior as evidence saves individual time and cognitive efforts (Cialdini and Trost, 1998; Cialdini, 1993).

**Injunctive norms**

By perceiving what other people approve or accept, it specifies what "should" be done. If others' expectations are important for us, they might influence our particular behavior. In this article the rewards or punishments brought by injunctive norms are only social sanctions but not legal ones.

**Subjective norms**

Fishbein and Ajzen (1975, p302) define subjective norm as "the person's perception that most people who are important to him think he should or should not perform the behavior in question".

**Social impact**

Latané (1981) describes social impact as the influence of other persons on an individual. The impact from the source of other people depends on three elements: strength of the source (e.g., the source's importance, credibility, and power), the proximity to the individual, and the number of other people constituting the influence source. Increasing the number has a decreasing marginal effect, which means, with the number of other people increases, the impact of others on the individual increases, but the increase rate goes down as new one is added.

Tanford and Penrod (1984) propose a social influence model. The amount of influence is an S-shaped function of the number of sources of influence. Beyond the limit of group size increasing the number has no additional impact.

**Compliance**

Compliance refers to the individual is urged to respond in a desired way. Cialdini and Trost (1998) review the practices of commercial compliance professionals and summarize six principles which seem to influence behavioral compliance decisions most: Conform to authority figures; Follow actions of similar others; Seize scarce opportunities; Accommodate requests of people we know and like; Reciprocation—something in return; Be consistent with prior commitments.

**Social comparison**

Festinger's (1954) social comparison theory assumes that people have a drive to evaluate their beliefs and behaviors in terms of their correctness or appropriateness. If objective evidence is not available, people seek social comparison evidence—beliefs or behaviors of others as a source of information—for the evaluations, especially from similar others for comparison.

## 4.2 Social influence studies of electricity saving behavior

Studies below are field experiments if not specified. Results of social norms effect are very heterogeneous (see Table 1). Some studies reported the effect in quantity, some found a correlation relationship between social norms and conservation behavior, some concluded that social norms are important motives, and some found no difference with or without normative feedback. The reasons could be different sizes of experimental groups/survey sample, households with various cultural aspects or types (household size, socioeconomic status), and the way social norms integrated in studies. Normative feedback was usually combined with other intervention techniques in experiments, and given in graphical displays or bills. In many studies, social norm approach is presented as comparative feedback—receiving others' consumption information for comparison. But the impact of social comparison is sometimes difficult to separate from household own consumption feedback or goal settings.

Haakana el al (1997) suggest the Finnish electricity saving potential lay between 83 and 125 kWh per month, which means households are able to decrease consumption by 11-16% (including electric heating) on average without compromising comfortable level or extremely changing habits.

Delmas et al (2013) performed a meta-analysis of information-based energy conservation experiments from 1975 to 2011. On average, individuals in the experiments reduced electricity consumption by 7.4%. Among different types of information strategies on energy conservation (individual usage feedback, energy saving tips, real time feedback, audits and consulting, monetary savings info, monetary incentives and social comparisons), field studies using social comparisons had the second highest average energy savings of 11.5%, followed by energy audits with 13.5% savings.

**Table 1. Studies of social influence on electricity saving behavior**

| **Author (year)** | **Key findings** | **Data and Country** |
|---|---|---|
| Allcott (2011) | Providing descriptive normative information led to an average residential energy saving of 2.0% (effects range from 1.4%-3.3% of baseline usage). | US, nearly 600,000 households |
| Ayres et al (2009) | Reports with neighbor comparison feedback (with both normative and injunctive messages) can lead to energy savings of between 1.2% and 2.1%. | US, 85 000 households |
| Dünnhoff and Duscha (2008) | Electricity annual bill with normative comparison did not show statistically significant differences in reported conservation activities nor in electricity consumption. | 4500 German households separated in experimental groups and one control group |
| Ek and Söderholm (2010) | Social interactions are important determinants of electricity saving activities within Swedish households. | 1200 Swedish households (survey) |
| Garay and Lindholm (1995) | There was no clear impact on electricity usage from monthly bills with historic and comparative feedback. But interviews showed that the bill improved households' sense of control over their energy costs. | Sweden, 600 households |
| Göckeritz et al (2010) | A positive correlation between descriptive normative beliefs and energy conservation behavior was found (r = .37, $p < .01$). Injunctive normative beliefs showed a positive relationship with conservation behavior (b = .14, $p < .01$). High | 1604 US residents (telephone survey) |

| | | |
|---|---|---|
| | injunctive normative beliefs can strengthen the impact of descriptive normative beliefs on behavior. | |
| Haakana el al (1997) | All groups had consumed less electricity after compared with own consumption of same months in the previous year. 83% of the households wanted comparison with other similar houses. | Finland, 105 single-family houses, with three experimental groups and one control group |
| Harries et al (2013) | Electricity feedback with social norm information was not found to reduce consumption. | UK, 1 participant for control and 16 participants for focus groups (in-depth interview); 316 participants in an 18-week experiment (with survey) |
| Loock et al (2011) | The combination of descriptive and injunctive normative feedback motivates both above- and below-average energy consumers to reduce consumptions. | Austria, 220 customers of a utility company in experimental groups |
| Loock et al (2012) | Social norm interventions are successful in motivating energy conservation. Close reference groups in geographical proximity are more effective than distant groups. Energy consumers living in rural areas with stronger social ties might be more affected by social normative feedback than urban residents. | Austria, 322 households |
| Mi et al (2011) | Social norms have indirect effect (0.18) (via behavior intention) on low carbonization energy using behavior. | China, 280 urban residents (survey) |
| Nolan et al (2008) | Descriptive normative beliefs were found to be the strongest predictor of individual energy conservation behavior ($r = .45$, $p < .01$). The use of normative | US, 371 households (meter data from 271 households) |

| | | |
|---|---|---|
| | messaging can achieve household energy savings of 10%. | |
| Peschiera and Taylor (2012) | Peer network norms are effective in promoting the implementation of energy saving practices. | US, 22-room study group |
| Petkov et al (2011) | Participants preferred to be in comparison with friends rather than similar users or neighbors. | Australia, interview of 17 EnergyWiz (a mobile application) users |
| Schultz et al (2007) | Participants above average consumption level reduced electricity consumption of 5.7% after receiving descriptive norm message. Low electricity users increased consumption of 7.9%, but remained low if injunctive norm was added. | US, 290 households |
| Sernhed et al (2003) | Households are more interested in comparison with own historical consumption than with other households. | Sweden, 3000 household customers from three electricity utilities, approximately 35% response rate (survey) |
| Thøgersen and Grønhøj (2010) | Perceptions about other household members' behaviors in saving electricity influence the individual's electricity saving intentions both directly and indirectly, especially via social outcome expectations. | Denmark, 320 private electricity consumers from 237 households (survey) |
| Ueno et al (2005) | Most residents are more interested in comparison with other houses than own past data. | Japan, 19 households in neighborhood |
| Wilhite et al (1999) | Bills with normative comparisons with other households of similar type and size show desired effects of increasing awareness of and motivating energy conservation. | Norway, 2000 households (field experiment) |

## 4.3 Social influence studies of technology adoption

Social norms can facilitate consumer engagement in sustainable technology. Condelli et al. (1984) stated that social network plays an influential role in innovation diffusions (more than mass media). Interview results from Alolayan (2014) found that some participants' intentions to use a smart fridge are influenced by their friends, colleagues and the community. The survey results of AlAbdulkarim (2013) found social influence has indirect effect via performance expectancy on smart meter acceptance but no significant direct effect. Kranz and Picot (2011) found groups like family members or friends significantly influence the intention of smart meter adoption.

For adoptions of smart appliances or smart grid, in general, economic and environmental benefits, privacy and security, and usability issues are more heatedly discussed but not social influence. The information system and IT related research however has discovered that social influence plays an important part in adoption decisions (Venkatesh and Brown, 2001), especially in decisions involving uncertainty (Fenech and O'Cass 2001). Social influence has directly or indirectly effects (via attitude) on intention to use an information system (Venkatesh and Morris, 2000; Venkatesh et al., 2003; Hong and Tam, 2006; Schepers and Wetzels, 2007; Venkatesh et al, 2012). Schot (2011) reviewed a few field experiments involving various behaviors. It found a trend that using normative messages are expected to cause an increase in the desired behavior by 20-25%. Schot (2011) conducted an intervention study to verify the effect of descriptive norms on IT usage behavior. The results showed that social norms significantly stimulate individual IT use. The intervention was more likely to motivate the individual if there were more similar peers already using the system.

For PV diffusion, social influence (e.g., peer effects, social comparison) was recognized as an important driver in several studies (see Table 2). As solar panels are visible, one sees neighbors benefiting from PV installations and becomes more aware of the available and viable option, and then the person is more likely to install a PV system. The local social networks can help educate individuals on the solar panels as well (Rothfield, 2010). Jager (2006) contended that social comparison processes facilitate information exchange both on the satisfaction and technical & administrative procedures of owning a PV system. This would reduce perceived uncertainty about this technology and make it more favorable for adoption. The more people in a social network who already installed PV, the more information will be available and the more strong this observability effect stimulate further diffusion. The effect may be crucial for decision-makings particularly in the complex context. Bollinger and Gillingham (2012) have found the significant peer effects of previous installations on the decision of a household to install solar in California and the effect will decrease with distance. Müller and Rode (2013) witnessed the same effect and confirmed the peer effect of PV adoption in the city of Wiesbaden, Germany.

**Table 2. Studies of peer effects on PV adoption**

| **Author (year)** | **Key findings** | **Data** |
|---|---|---|
| Bollinger and Gillingham (2012) | At the average number of owner-occupied homes in a zip code, 1% increase in installations increases the probability of an adoption in the zip code by 0.78 percentage points. | California, zip codes of PV installers |
| Graziano and Gillingham (2014) | Spatial peer effects positively affect the PV diffusion up to four miles and 24 months. And the effect diminishes over time and space.<br>One additional installation within 0.5 miles within six months earlier increases the number of installations in a block group by 0.44 PV systems per quarter on average. | Connecticut (US), geocoded data of PV installations from 2005 to September 2013 |
| Kwan (2012) | ZIP codes with higher rates of residential PV systems seem to influence neighboring ZIP codes to have similar PV shares. | ZIP code data from 2000 US census and data on individual solar PV installations |
| Richter (2014) | At the average number of 6629 owner-occupied households within a postcode district, an | UK, PV installation data between April 2010 and March 2013 |

| | | |
|---|---|---|
| | additional installation increases the number of new installations in the neighborhood by 0.05. | |
| Rode and Weber (2012) | The peer effect will decrease with distance and localized imitation can only be significantly identified up to a range of 1.2 km. | Germany, PV diffusion between 1992 and 2009 |
| Welsch and Kühling (2009) | The behavior of reference persons (e.g., friends, neighbors and relatives) is highly important for adoption of solar thermal system. | Hanover (Germany), a survey conducted in 2007, 139 owners of solar thermal systems |

## 4.4 Different perspectives of social influence

In order to guide later explorations of aggregated behavior changes, several perspectives of social influence are abstracted from the glimpse of relevant concepts and studies, which are: social influences on individual action; social norms as intervention and marketing strategies; social influence occurring through the process.

**Social influences on individual action**

Individual behavior forms the basic unit of analysis in the thesis and is constrained by social norms perceived by people. Theory of reasoned action acknowledges the social influence on personal behavior by incorporating subjective norm on behavioral intention. In the updated theory of planned behavior (Fishbein and Ajzen, 2010) use the term “perceived norm” to cover both injunctive and descriptive norm with respect to a particular behavior.

What important others think of my actions and my belief about others’ behaviors in the same situation constrain my individual intentions. Individuals intend to comply with social referents, because people want being liked by group members, or making correct decisions, or avoiding costs associated with defying norms. The thesis focuses on the interpersonal influences from reference groups such as friends, family members and neighbors.

**Social norms as intervention and marketing strategies**

As social norm is one influential determinant of behavioral intention, normative feedback is often used to increase the effectiveness of feedback interventions. Social norm interventions usually use descriptive norms (what relevant others do in the given situation) and/or injunctive norms (what relevant others think people should do) with which people can compare their own behaviors. Trying to prevent boomerang effects, adding injunctive message to descriptive normative information may make it possible that people above the norm do not feel that they deviate from others and do not decrease targeted behaviors. And the same message could serve to increase desirable behaviors of individuals below the norm (Schultz et al, 2007).

Also, social norms are increasingly being employed in social norm marketing to inspire people to pursue appropriate behaviors, particularly in the context of socially responsible behaviors (Melynk et al, 2010). Social-norm marketers could infer the social norm at the aggregate level, especially where social norms might not be known to the individuals.

However, evidence for the effectiveness of social norms in behavioral changes is mixed. Possible explanations are: Firstly, normative feedback is usually presented to people alongside other intervention techniques. It is not easy to distinguish the impact of social comparison from other used techniques like individual feedback (e.g., historical consumption) (Harries et al, 2013). Secondly, descriptive and injunctive norms should be aligned. Thirdly, social norms interventions or campaigns could be very effective if appropriate reference group (perceived relevance) is provided, as it requires the information about others' behaviors and expectations to trigger the need for comparison.

**Social influence occurring through the process**

For prosocial products and behaviors (pro-environmental technologies and behaviors), people are more aware of others' actions and expectations. Prosocial goals cannot be achieved by individuals alone. It relies on subsequent adoption decisions of others

(Axsen, 2010). The diffusion of a prosocial product begins with one initial group of individuals with high levels of interest who are willing to take up the new product or practice (Oliver et al, 1985; Axsen and Kurani, 2012a). These enthusiasts with prosocial motives test and promote it, probably bearing high initial costs, intentionally disseminate information on the attributes of innovative technologies or practices (e.g., costs and benefits) over their interpersonal networks, through which to positively influence future adopters and induce the diffusion and conformity.

Innovative technologies or practices diffuse as the information flows through social networks. The adoption process is driven by communication from earlier adopters to potential consumers (Rogers, 1983). Conformity occurs through one consumer's perception of how many others have already adopted. The threshold approach is often used, which emphasizes the perceived presence of prior adopters in the individual's personal network before he or she adopts. With more people in the personal network that have adopted a certain behavior, the individual would be more likely to adopt (Axsen and Kurani, 2012a). Jager (2006) contended that social comparison processes facilitate information exchange both on the satisfaction and technical & administrative procedures of owning a PV system. This would reduce perceived uncertainty about this technology and make it more favorable for adoption. The more people in a social network who already installed PV, the more information will be available and the more strong this observability effect stimulate further diffusion.

Condelli et al. (1984) stated that social network plays an influential role in innovation diffusions (more than mass media). Diffusion of innovation theory also emphasizes the spread of adopting new products due to interactions within social networks. Therefore, the structure of relationships among individual consumers will influence diffusion processes. For example, the connectedness of individuals in the network determines the speed of aggregate adoptions.

# 5. Survey

The aim of the survey was to capture factors influencing private electricity use, acceptance of smart grids and willingness to install solar panels on the roof. Therefore the questionnaire consisted of five parts, which are electricity consumption, opinions about smart grids, energy efficiency, renewable energy and electricity generation, and demographic characteristics, including a total of 81 questions (see Appendix).

The questionnaire was written in German and was pre-tested by around 15 people at ZIRIUS (http://www.zirius.eu/), University of Stuttgart. Unfortunately, there was no money available to do random sample pre-test or representative sample survey. This is a convenient sample to investigate TPB constructs. Respondents are people (living in Germany) who replied email invitations for the online survey about individual energy consumption. The “SurveyMonkey” online survey tool was used to collect data. The first page of the survey was a cover letter stating the significance of this research, with short explanations about data protection and how to fill out the questionnaire. Data were anonymously collected. 5-point Likert scales were employed for most items from “is absolutely true” to “is not true at all”.

## 5.1 Assumptions about the survey sample

Email invitations were sent to people who have been involved in energy-related research or citizen groups with interest in energy. Assumption 1): Invited people are supposed to show higher interest and have more knowledge about energy topics than the general public.

People with relatively high interest in the energy topic tend to respond to the survey. Assumption 2): Respondents are supposed to have higher interest in energy topics compared with the general public.

## 5.2 Characteristics of the survey respondents

During the period of November 17, 2013 to January 31, 2014, 645 German citizens[2] participated in the survey, and 517 complete cases can be used for further data analysis. Response rate cannot be calculated, as some email invitations were sent to email lists which belong to certain research group or citizen groups in the energy field, and it is difficult to find out the exact numbers of activated group members in the lists.

Table 3 shows the demographic data about the respondents. It can be seen that in the survey sample women are underrepresented. Male citizens, people with higher education or higher income, tend to answer the survey. For additional explanation, the education question is asked according to German education system, respondents are expected to choose the level of school they have completed from the options of no degree, low level, medium level to higher levels.

**Table 3. Demographic characteristics of the survey sample in comparison with German official data at the end of 2013**

| Characteristics | Category | N (Percentage) | Official-Percentage |
|---|---|---|---|
| **Gender**[3] | women | 179 (35.3%) | 51% |
| | man | 328 (64.7%) | 49% |
| **Education: Highest level completed**[4] | No degree (ohne Abschluss) | 2 (0.4%) | 7.5% |
| | Volks-Hauptschulabschluss | 10 (2.0%) | 34.7% |

[2] The questionnaire uses German language. And for the education item, no respondents received highest degree outside Germany. Therefore, it assumes that they are German citizens. But a question asking about nationality would be more convincing.

[3] The official data source: https://www.destatis.de/DE/ZahlenFakten/GesellschaftStaat/Bevoelkerung/Bevoelkerungsstand/Tabellen/Zensus_Geschlecht_Staatsangehoerigkeit.html

[4] The official data source: https://www.destatis.de/DE/ZahlenFakten/GesellschaftStaat/BildungForschungKultur/Bildungsstand/Tabellen/Bildungsabschluss.html

| | | | |
|---|---|---|---|
| | Mittlere Reife | 25 (4.9%) | 29.3% |
| | Fachhochschul- oder Hochschulreife | 89 (17.4%) | 13.8% |
| | Fachhochschul- oder Hochschulabschluss | 299 (58.5%) | 13.6% |
| | Doctor degree (Promotionsabschluss) | 86 (16.8%) | 1.1% |
| **Living status**[5] | owner | 239 (46.2%) | 43% |
| | renter | 278 (53.8%) | 57% |
| **Net Income**[6] | Less than 1300 € | 68 (13.8%) | 26% |
| | 1301-2000 € | 78 (15.9%) | 23% |
| | 2001-2600€ | 78 (15.9%) | 15% |
| | 2601-5000€ | 202(41.0%) | 28% |
| | More than 5000 € | 66 (13.4%) | 8% |

## 5.3 Preliminary survey results

Statistical analysis with SPSS version 21 was used to analyze data. It was found that the sample has an average age of 41 years (SD = 14, range: 18-75) with higher education and higher income. In case of reference the coding of question items is provided in the Appendix.

[5] The official data source: https://www.destatis.de/DE/ZahlenFakten/GesellschaftStaat/EinkommenKonsumLebensbedingungen/Wohnen/Tabellen/HuG_Wonflaeche_AnteileEVS.html

[6] The official data is in year 2011, referring to sources: GENESIS-Online Datenbank, and Private Haushalte—Einkommen, Ausgaben, Ausstattung: Auszug aus dem Datenreport 2013, p144.

### 5.3.1 As private electricity consumers

Households, as end users of electricity, consume electricity and pay the energy bill. As electricity is considered as a necessity, consumption seems to be price inelastic. However, in the case of reducing expenses or corresponding environmental impacts, it is possible that households consider cutting electricity use or adopting energy-efficient appliances to save energy. The electricity consumption is largely dependent on the household size, ownerships of appliances and energy efficiencies of appliances (Mills and Schleich, 2010). From these aspects, related analysis results will be described below.

512 participants answered the household size questions (V1a and V1b, see Appendix), and the distribution is shown in Table 4. The average household size of the sample is 2.56 (SD = 1.324). The V1c question about monthly electricity cost estimation in the household only obtained 470 responses (with around 9.1% missing values). The estimated costs range from 10 Euro to 385 Euro, with the average value of 69 Euro (SD = 46.9). As private consumers consume electricity through domestic appliances, in the survey participants were asked to report home appliances they own (Question V3) and all (N = 517) have answered this question. As shown in Table 5, almost all respondents (99.6%) own a refrigerator at home, the vast majority (98.5%) of households owns a washing machine and 98.3% of households have a computer at home. Analysis also indicates that households with higher income tend to own tumble dryers or dishwashers. Households without children are less likely to own a tumble dryer or dishwasher. Nevertheless, about half of dryer owners and households without tumble dryers prefer hanging clothes out to using the dryer (Question V7c).

**Table 4. Distribution (in percentage) of household size**

| | |
|---|---|
| 1 | 18.4% |
| 2 | 43.2% |
| 3 | 15.8% |
| 4 | 14.1% |
| ≥5 | 8.5% |

Note: N = 512

**Table 5. Ownership of electrical appliances**

| Appliance | Number of households with one or more | Percentage of households with one or more (%) |
|---|---|---|
| Refrigerator | 515 | 99.6 |
| Washing machine | 509 | 98.5 |
| Computer | 508 | 98.3 |
| Bake oven | 477 | 92.3 |
| Electric stove | 457 | 88.4 |
| Dishwasher | 385 | 74.5 |
| Coffee machine | 315 | 61.0 |
| Microwave | 268 | 51.8 |
| DVD player | 204 | 39.5 |
| Tumble dryer | 152 | 29.4 |
| Playstation/Xbox/Wii | 73 | 14.1 |
| Electric heating | 57 | 11.0 |
| Projector | 24 | 4.6 |

Question V28 asked how frequently participants use the appliances shown in Table 6. Owners represent those who have reported the ownership of appliances for Question V3. Sample size is the number of responses obtained for the frequency question V28. From Table 6 it can be seen that question items have some missing values. The washing machine item has the least missing values about 2.6% and the tumble dryer item has the most missing values about 6.6%. Frequencies of using different appliances depend on the lifestyle of each household. On average, electric stove is more often used and bake oven is less used at home. Only a small part of households own a tumble dryer, and dryer is not used so frequently. A medium correlation was found between the number of washing machine cycles and the number of dryer cycles (Pearson's $r = 0.488$, $p < .01$).

**Table 6. Usage frequency of common appliances (Unit: Number of times per week)**

| Appliances | Number of owners | Sample size | Minimum | Maximum | Mean | Standard Deviation (SD) |
|---|---|---|---|---|---|---|
| Washing machine | 509 | 496 | 0.20 | 15 | 2.78 | 1.99 |
| Bake oven | 477 | 452 | 0.05 | 15 | 1.82 | 1.68 |
| Electric stove | 457 | 435 | 0.25 | 25 | 5.86 | 3.57 |
| Dishwasher | 385 | 374 | 0.20 | 14 | 3.44 | 2.23 |
| Tumble dryer | 152 | 142 | 0.05 | 10 | 2.20 | 1.80 |

For electricity saving (Question V8d: “It will be easy to reduce my electricity consumption by 10%.”), only 8.3% of respondents (N = 468) strongly agree that it is easy to reduce 10% of own consumption, 24.4% of respondents agree, 34.8% of respondents disagree, and 7.9% of respondents strongly feel it is too difficult. The rest are people who have not made a clear evaluation yet. Cross-table analysis was conducted between question item V8d and V8e (“If I have more information about my electricity use, I am likely to consume less.”). It was found that information could be a barrier of electricity saving (chi-square = 157.406; $p < .001$). For people who need more information to help reduce electricity consumption, half of them agree that they have saving potential, which is easy to reduce 10% of own consumption. For people who perceived having enough information[7], approximately 60% of them feel it would be difficult to reduce 10% of electricity consumption. One explanation could be they have already tried to save electricity as they got the information needed, therefore, further savings for them are more difficult than people who still need information. This was confirmed by the result that 54% of respondents who perceive saving 10% easy lack information, while 32% of respondents with enough information see saving 10% easy.

Questions V5 and V6 asked respondents to choose the source and frequency of electricity saving information they acquire. The sources were: newspaper, professional journals, TV/Radio, Internet, brochure, information event and personal consultation. 499 participants answered the source question. Internet is the most popular information channel, as 87% of the respondents obtain electricity saving information from Internet. The following information sources used often are newspaper (51.3%), TV/Radio (49.3%) and brochure (47.5%). 26.7% of respondents perceived they obtained information about saving electricity very frequently. 28% of respondents got related information frequently. 42% of respondents were seldom informed and only 3.3% never

[7] Cross-table analysis between question item V5 (frequency of electricity saving information acquired) and V8e shows that respondents who agree more information cannot help consume less electricity are much more frequently informed than people who still need information. It indicates that the well-informed people have enough information that they need.

heard about electricity saving. Question V2 asked participants how frequent they would like to be informed about electricity consumption. 34.1% of respondents (N = 513) prefer it stays as it was. Only 7.8% of respondents hope to receive information every week. Most others would like to receive information 3-4 times each year, maximum one time every month. In consistent with discussions above, cross-table analysis between question item V2 and V8e ("If I have more information about my electricity use, I am likely to consume less.") shows that respondents with enough information would like to be less frequently informed than people lack information.

Energy efficiency levels of each household are measured by question V26 (TV) and V27 (lighting). In general, conventional light bulbs and Halogen bulbs are the least energy efficient and LED bulbs are the most efficient. LCD/LED TV are the most efficient, while standard CRT TV and Plasma TV cost more energy than LCD/LED TV[8]. A rough categorization of efficiency levels for households comes out according to their ownership of these appliances. It was found that 9.7% of households (N = 517) have low efficiency levels, 51.6% of households have medium efficiency levels and 38.7% have high energy efficiency.

In European countries, many home appliances such as washing machines carry energy labels with an indication of energy consumption, which can help customers choose energy efficient products. Question V25 investigated whether participants notice the Energy labels on electric appliances. The majority (78.3%) of respondents (N = 512) report seeing such labels very often. 13.3% of respondents saw this energy label often. 6.1% of respondents rarely saw the labels and 2.3% did not notice.

For some appliances like dishwashers, eco or energy-saving programs have been designed. Computers also have power saving mode. To save energy when there is no activity for a prolonged period of time, appliances such as TV can be operated in standby mode. Question V29 tried to examine how households perform in these aspects, as shown in Table 7. It was measured on a 5-point scale from 1= "is absolutely true" to

[8] This is rough estimation under the assumption that the sizes of all TVs are similar.

5= “is not true at all”. Results show that more than half of the respondents use eco program when using washing machines or dishwashers. Approximately 53% of the respondents use computers in power saving mode. Few people (5%-10%) use standby mode of appliances like TV and DVD player when not using them for a long time, and the vast majority would then shut them down completely.

**Table 7. Settings on home appliances**

| Question | N | Mean | SD |
|---|---|---|---|
| Using eco program of the washing machine | 453 | 2.14 | 1.245 |
| Using eco program of the dishwasher | 359 | 1.96 | 1.168 |
| Using power saving mode of the computer | 475 | 2.56 | 1.385 |
| Complete shutdown of appliances like TV and DVD player when not using for a long time | 476 | 1.67 | 1.146 |

To capture factors influencing respondents’ adoption of energy-efficient appliances, factor analysis was conducted concerning question V30 (see Appendix). The result is shown in Table 8, and loadings < .30 are not displayed in the table. Two factors with an eigenvalue above 1 are identified for adoption of energy-efficient appliances. Factor 1 can be interpreted as dimensions of energy performance and the environmental impact. Factor 2 can be interpreted as economic perspective such as costs and financial considerations.

**Table 8. Rotated Component Matrix for efficiency items (varimax rotation)**

| | Factor | |
|---|---|---|
| | 1 | 2 |
| 1. When buying an appliance, its electricity consumption is very important to me. | .841 | |
| 2. Price of the appliance is more important than its electricity consumption to me. | -.723 | |
| 3. If there are favorable financing or rebates for the purchase of energy efficient appliances, I would like to buy one. | | .649 |
| 4. Before I spend money on an efficient appliance, I would like to know more about its benefits. | | .788 |
| 5. I will purchase energy efficient appliances, because it saves money in the long term. | .630 | .466 |
| 6. I will purchase energy efficient appliances, because protecting the environment is very important to me. | .761 | .345 |
| Eigenvalue (unrotated values in parentheses) | 2.22(2.50) | 1.45(1.17) |
| Percentage of variance explained (unrotated values in parentheses) | 36.9(41.6) | 24.1(19.5) |

Extraction Method: Principal Component Analysis.

### 5.3.2 Participation in smart grid applications

In the context of German energy transition (Energiewende) whose aim is to increase renewable energy shares, smart grid will play a key role in managing the demand able to match the volatile green energy supply. As Energiewende is heatedly discussed in Germany, smart grid is also brought to the table and earning some attention. Smart meter and smart appliances as key elements of smart grid, their development cannot succeed without customer acceptance. Analysis about consumer preferences related and the forms of load management consumers could accept will be described below.

21.8% of respondents (N = 513) have been informed about smart grid topics very often. 18.4% of respondents often heard about smart grid. 38% of respondents occasionally heard something about the topic and 21.8% knew nothing about smart grid. Smart grid is a complex concept, as the survey sample with higher education and higher interest in energy topics (see Section 5.2), for which the general public will have much lower level of knowledge. A medium correlation was found between the level of knowledge regarding Energiewende and the level of knowledge regarding smart grid (Pearson's r = 0.667, $p < .01$). The cross-table analysis between question items V9a and V9b (see Table 9) also indicates that the more people know about Energiewende, the more likely they are to know something about smart grid.

**Table 9. Crosstab for knowledge of Energiewende and Smart grid**

| | | | Smart grid | | | | | Total |
|---|---|---|---|---|---|---|---|---|
| | | | Yes, very often | Yes, often | Yes, occasionally | Yes, seldom | No, never | |
| Energiewende | Yes, very often | N | 107 | 59 | 55 | 10 | 12 | 243 |
| | | % within Energiewende | 44.0% | 24.3% | 22.6% | 4.1% | 4.9% | 100.0% |
| | Yes, often | N | 2 | 29 | 46 | 32 | 27 | 136 |
| | | % within Energiewende | 1.5% | 21.3% | 33.8% | 23.5% | 19.9% | 100.0% |
| | Yes, occasionally | N | 0 | 2 | 23 | 16 | 44 | 85 |
| | | % within Energiewende | 0.0% | 2.4% | 27.1% | 18.8% | 51.8% | 100.0% |
| | Yes, seldom | N | 0 | 0 | 1 | 6 | 19 | 26 |
| | | % within Energiewende | 0.0% | 0.0% | 3.8% | 23.1% | 73.1% | 100.0% |
| | No, never | N | 0 | 0 | 0 | 0 | 9 | 9 |
| | | % within Energiewende | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% | 100.0% |
| Total | | N | 109 | 90 | 125 | 64 | 111 | 499 |
| | | % within Energiewende | 21.8% | 18.0% | 25.1% | 12.8% | 22.2% | 100.0% |

Approximately 80% of respondents feel that they know Energiewende quite well including its advantages and disadvantages, have faith in its realization and support the aims (Question V11). Results of questions V16 and V17 show that 9.2% of the respondents (N = 469) think that Energiewende will bring negative impact to the branch they work in (mainly traditional energy utility companies). 53.7% of the respondents think that Energiewende will impact positively on the branch they work in (mainly public sector, renewable energy sector and research field). 37.1% of the respondents think that Energiewende will influence the branch they work in (mainly public sector and research field) neither positively nor negatively. For smart grid, about half of the respondents (N = 470) have a great idea of its pros and cons (Question V12a), with additional 43 respondents have no idea at all. The cross-table analysis between question items V11c ("I would like to support the aims of Energiewende.") and V12c ("If my electricity supplier makes it possible for me to participate in smart grid applications, I will be very likely to take part.") shows that more than 60% of respondents who support Energiewende would be also willing to participate in smart grid applications.

To bear costs of the Energiewende, households are charged for some surcharges like renewable energy surcharge (EEG-Umlage) in the electricity bill. Then renewable energy surcharge pays the feed-in tariff for renewable energy development. Concerning this issue, 40.8% of the respondents (N = 507) think that German electricity price will still go up in near future. 24.1% of the respondents think that German electricity price will increase first but decrease afterwards. 28.8% of the respondents think that German electricity price will fluctuate. Very few others think that the price will decrease or keep the same (Question V14). Nevertheless, without Energiewende 65.1% of the respondents (N = 510) think that the electricity price will be definitely increasing in future (Question V15). Household income (Question V46) and the presumptive income change[9] (Question V47) were found to have no relationships with the expectation of future electricity price in Germany (Question V14).

Questions V10 asked respondents to choose the information sources they use to learn about Energiewende and smart grid. The sources were: newspaper, professional journals, TV/Radio, Internet, brochure, information event and personal consultation. Internet is the most popular information channel, as around 85% of the respondents (N = 500) acquire information about Energiewende from Internet and 77% (N = 379) for smart grid. The following information sources used often for Energiewende are newspaper (71.4%), TV/Radio (62.2%) and professional journals (46.4%). The following

[9] 40% of the respondents (N = 498) think that their income will keep the same in future, and 33.5% think that their income will increase in near future.

information sources used often for smart grid are professional journals[10] (52.2%), newspaper (51.2%) and TV/Radio (40.4%).

Smart meter, as an important element of the smart grid, can inform households their real-time consumptions and could provide the gathered data to utilities for monitoring and billing as well. 8.2% of the respondents (N = 497) has installed a smart meter at home, 2.4% planned to do so and the rest did not install it (Question V13). 43.6% of the respondents (N = 489) highly trust their electricity providers to handle the consumption data, while 29.7% show little trust (Question V21). 52.3% of the respondents (N = 499) agree that their electricity providers gather the consumption data so as to help balance supply and demand, while 24.4% do not agree (Question V22). The cross-table analysis between question items V21 and V22 indicates that the higher trust people have in their electricity providers, the more probably they will agree with their consumption data to be gathered. Question V23 asked participants about the electricity providers they are using, municipal utilities (Stadtwerke) are mentioned the most. EnBW is also used by many respondents, as citizens from the state of Baden-Württemberg account for 62.5% of the sample (Question V48). Companies which provide green electricity[11] like EWS (Elektrizitätswerke Schönau) and Greenpeace Energy are used by some respondents too. Only 25.6% of the respondents (N = 461) did not switch to green electricity, while 56.2% are using green electricity and 18.2% use green electricity partially (Question V24).

For smart appliances which can be automatically controlled, question V4 asked participants whether they can imagine using such appliances as shown in Table 10. It was found that dishwashers and washing machines have the highest acceptance rate. Bake oven has the lowest acceptance rate. In addition, there are still some people who do not know and cannot make a judgment yet, which are labeled as “no idea” below.

[10] The reason why professional journals take such an important part is that some energy researchers are involved in the survey.
[11] The electricity is obtained from renewable energy sources.

**Table 10. The distribution of smart appliances that can be accepted by households**

| Appliance | N | Percentage of acceptance (%) | Number of "no idea" |
|---|---|---|---|
| Bake oven | 427 | 12.9 | 47 |
| Washing machine | 484 | 75.0 | 28 |
| Tumble dryer | 344 | 69.8 | 55 |
| Dishwasher | 464 | 77.2 | 24 |
| Electric heating | 293 | 45.4 | 69 |

Question V18 asked participants to rate (scale from 0-10, the higher, the better) their preferred options dealing with the energy demand under no wind and no sunshine circumstances. For each option, there is someone who gives a score of 0 or 10. As shown in Table 11, the least preferred option would be using "fossil energy", while the most acceptable option would be "small decentral energy storage", followed by "large central energy storage" and "reduction of electricity consumption through contracts", which is consistent with the top 3 options accepted in question V19.

**Table 11. Rating of options dealing with the energy demand under no wind and no sunshine circumstances**

| Option | N | Mean | SD |
|---|---|---|---|
| Energy import from other countries | 446 | 3.68 | 2.868 |
| Fossil energy (oil, gas, coal) | 484 | 2.81 | 2.571 |
| Large central energy storage | 486 | 7.08 | 2.528 |
| Small decentral energy storage | 484 | 7.13 | 2.692 |
| Reduction of electricity consumption when electricity price is very high (e.g., at peak hours) | 481 | 4.75 | 3.208 |
| Reduction of electricity consumption through contracts of agreeing to shut down energy intensive appliances at peak hours | 483 | 5.88 | 3.202 |
| Reducing a predetermined maximum quantity of electricity at peak hours | 473 | 3.63 | 3.100 |

When dealing with limited electricity supply under no wind or no sunshine circumstances, participants were given three kinds of electricity tariffs to be involved in reducing load on the grid (Question V20):

1. When there is little power available, the price goes very high; when there is a lot of power available, the price becomes very low.

2. When there is little power available, it allows the installed home storage to provide electricity for basic needs such as lighting, fridge and freezer.

3. When there is little power available, your home electricity will be cut off for maximum 2 hours. For each hour out of electricity you will receive 10% rebate of your electricity costs for that month.

The results show that option 2 is the most acceptable, followed by option 1 and option 3. 77.6% of respondents (N = 487) think that option 2 is possible and can be considered, while 13.8% reject it. 46.8% of respondents (N = 489) can consider tariff 1 as an option, 38.7% reject it and 14.5% have not decided to accept it or not. Only 14.8% of respondents (N = 486) do not mind tariff 3 as an option, while 49% strongly reject it and 23.3% reject it.

### 5.3.3 Acceptance of renewable energy technologies

This part will firstly describe opinions of the sample about renewable energy technologies such as wind and solar energy. Most people support their development generally. And for actual experiences, respondents have more with solar energy than wind power technologies. In the following their perceptions about home photovoltaics (PV) installations[12] will be discussed. Benefiting the environment was found to be the most important advantage. Costs of adopting home PV generation and its payback period are identified as constraint factors.

Questions V31 and V32 investigated citizens' general attitudes towards large-scale wind or solar farms. As the facilities were assumed to be located about 10 km away, the distance is not near enough to evoke strong resistance or NIMBY (not in my back yard) attitude. 75.8% of respondents (N = 508) support the development of a wind park, and only 8.9% oppose it. 78.5% of respondents (N = 507) support the development of a large solar farm, and only 5.1% oppose it.

For home renewable energy installations, 39.1% of respondents (N = 517) were never informed about it. 27.4% of respondents occasionally heard something, and 33.5%

[12] Solar panels were chosen as the focal technology for home generation in this study.

obtained the information often (Question V33). A medium correlation was found between the level of knowledge regarding home renewable energy installations and living status of the respondent as an owner or renter (Pearson's $r = 0.589$, $p < .01$). 86.6% of people who were never informed about the topic are renters.

Question V34 asked respondents to choose the information sources they use to learn about home renewable energy installations. The sources were: newspaper, professional journals, TV/Radio, Internet, brochure, information event and personal consultation. Internet is the most popular information channel, as around 79% of the respondents (N = 314) acquire such information from Internet. The following information sources used often are professional journals[13] (52.5%), newspaper (46.2%), and TV/Radio (42.4%).

Survey participants were also asked about their experiences related to wind or solar energy technologies (Questions V35 and V36), the results of which are shown in the following table. Wind turbines have requirements of wind resources, and sunshine is more common. Respondents likewise have more experience with solar energy than wind power. Hence later analysis (Section 6.2.3) will focus on home PV adoption.

**Table 12. Experiences related to wind and solar energy technologies**

| | **N** | **Yes (%)** |
|---|---|---|
| **Wind energy** | | |
| Near my living place there are wind energy facilities. | 493 | 34.7% |
| I know people who are involved in the construction and operation of wind turbines. | 498 | 41.8% |
| I/My family have/has invested in wind energy facilities. | 499 | 8.2% |
| **Solar energy** | | |
| Near my living place there are solar energy facilities. | 481 | 85.2% |
| I know people who have installed a rooftop solar system. | 504 | 86.7% |

[13] The reason why professional journals take such an important part is that some energy researchers are involved in the survey.

| | | |
|---|---|---|
| I/My family have/has invested in solar cells. | 502 | 29.5% |

In general, citizens have faith in the development of solar energy technologies, as 76.9% of respondents (N = 494) believe in future photovoltaics will be everywhere in Germany (Question V42a). But max. 59% of respondents (N = 428) would recommend acquaintances to install a rooftop PV system, and the rest either have not made a clear evaluation yet, or have no idea about it, or would not recommend it (Question V42c). Among the people who have invested in solar cells, 81.2% of them would recommend acquaintances to install a rooftop PV system.

Question V38 asked participants if possible whether they can imagine installing a rooftop solar system at home. 76% of respondents (N = 499) choose "yes", only 6.6% choose "no". Such high rate of approval (especially in comparison with 29.5% actually invested in solar cells[14]) is because it is an imaginary question excluding certain constraints in reality (e.g., living status as an owner or renter, economic aspects). The attitude towards home PV generation was investigated by question V39. It was measured on a 5-point scale from 1= "is absolutely true" to 5= "is not true at all". As shown in Table 13, the most important perceived advantage is for the environment which is followed by visual impact. Besides, 69.6% of respondents think installing home PV is a worthwhile investment. Surprisingly, the least important advantage here is independence from electricity supplier. Cost factor is a potential barrier, especially when a number of people are not clear about the maintenance costs. 26.4% of the respondents (N = 493) think that the payback period[15] for a rooftop PV system would be 5-10 years, while 40% feel it would 11-15 years and 24.1% choose 16-20 years. Only 2.8% of respondents think it would be less than 5 years. The rest respondents choose it needs at least 20 years, or even longer (Question V41). For the price of a photovoltaic system, 49.5% of respondents (N = 487) think that it will decrease in near future, 17.7% think it will keep the same, and 13.3% think it will fluctuate (Question V40).

[14] Due to consideration of citizens as renters, even if it is not possible for them to install PV on the roof, they could invest in collective solar parks, community shared solar energy projects etc.
[15] Time until the investment cost is recovered.

**Table 13. Attitudes towards home PV generation**

| It (is) | N | Mean | SD |
|---|---|---|---|
| Benefit the environment | 473 | 1.78 | 0.999 |
| Beautiful | 483 | 1.79 | 1.085 |
| Modern | 454 | 2.09 | 1.057 |
| Worthwhile investment | 464 | 2.17 | 1.121 |
| Reliable | 421 | 2.23 | 1.045 |
| Maintenance-infrequent | 381 | 2.28 | 1.017 |
| Not expensive | 456 | 2.51 | 1.226 |
| Independent from electricity supplier | 472 | 2.61 | 1.277 |

## 5.4 The application of TPB constructs

This part will describe the efforts made to apply the TPB model in predictors of target behaviors. Due to limited number of question items in the survey, some constructs were not well represented. The questionnaire should be better designed with at least three items to measure each construct, and then the results will be more convincing.

### 5.4.1 Electricity saving behavior[16]

In the survey there are 8 items (see Table 15) related to constructs of theory of planned behavior applied in electricity saving. As there are no items designed to examine behavioral intention, four factors (saving behavior, attitude toward saving, perceived norm, and perceived behavioral control) are supposed to be extracted. The principal component analysis (PCA) with oblique rotation (direct oblimin) was performed using SPSS version 21. It was found that correlations among factors are all less than 0.3, which indicates the extracted factors are relatively uncorrelated (Tabachnick and Fidell, 2007, p646). Therefore, the results of PCA with orthogonal rotation (varimax rotation) as extraction method are reported below.

[16] Later analysis focuses on curtailment behavior.

**Table 14. KMO and Bartlett’s test of sphericity (test statistics for items regarding electricity saving)**

| | | |
|---|---|---|
| Kaiser-Meyer-Olkin Measure of Sampling Adequacy. | | .698 |
| Bartlett's Test of Sphericity | Approx. Chi-Square | 379.277 |
| | df | 28 |
| | Sig. | .000 |

The result of KMO and Bartlett’s test of sphericity are shown in Table 14. The value of Kaiser-Meyer-Olkin measure of sampling adequacy is .698 and the Bartlett’s test of sphericity is ($p < .001$), which indicates the sample data are suitable for a factor analysis to proceed.

Communalities after extraction varied from 0.524 (item 3) to 0.983 (item 7). Table 15 shows the factor analysis result, and loadings < .30 are not displayed in the table. The four factors explained 69.9% of the total variance. As there is only one question item to capture the latent variable “Perceived behavioral control”, the divergence between factor 1 and 2 is not quite clear. Item 2 and item 3 have higher factor loadings on the second factor (Perceived behavioral control) instead of the first factor (Behavior of saving electricity). However, for the first four items which were supposed to represent the latent variable “Behavior of saving electricity”, it shows a Cronbach’s-α of .661 for the reliability statistics. Before the reliability calculation, item 2 and item 3 with negative expectations were reverse scored. Apart from measured items on behavior, other items have high loadings on their hypothesized constructs. Factor 3 (Attitude toward saving own electricity) and factor 4 (Perceived norm) related to electricity saving are clearly identified. As there are only two items measuring the construct “Attitude toward saving own electricity”, the value of Cronbach’s-α reliability is only .457.

**Table 15. Principal component analysis of items regarding electricity saving (varimax rotation)**

| | Factor 1 | Factor 2 | Factor 3 | Factor 4 |
|---|---|---|---|---|
| 1. I usually remember to turn lights off when I leave the room. | .873 | | | |
| 2. I usually leave the computer on even when I will not use it for a long time. | -.342 | .678 | | |
| 3. I leave appliances in Standby mode when they are not needed for long. | -.332 | .620 | | |
| 4. I pay much attention to whenever possible I could save electricity at home. | .737 | -.304 | | |
| 5. As long as big companies consume so much electricity as always, I don't think I should save electricity. | | | .824 | |
| 6. Whether I consumer some less or more electricity, it makes no different impact on the environment. | | | .782 | |
| 7. Most of the people who are important to me (e.g., friends/family, neighbors) think that I should save electricity. | | | | .989 |
| 8. If I have more information about my electricity use, I am likely to consume less. | | .769 | | |
| Eigenvalue (unrotated values in parentheses) | 1.62 (2.40) | 1.58 (1.32) | 1.37 (1.01) | 1.03 (0.86) |
| Percentage of variance explained (unrotated values in parentheses) | 20.2 (29.9) | 19.7 (16.5) | 17.2 (12.6) | 12.8 (10.8) |

Extraction Method: Principal Component Analysis.

### 5.4.2 Intention to participate in smart grid applications

In the survey there are 6 items (see Table 18) related to constructs of theory of planned behavior applied in smart grid acceptance. As there are no items to examine the real behavior involving consumers in smart grid applications, four factors (behavioral intention, attitude toward smart grid, perceived norm, and perceived behavioral control) are supposed to be extracted. The principal component analysis (PCA) with oblique rotation (direct oblimin) as extraction method was performed, as Table 16 shown the correlation coefficients among factors are substantial (all $\geq$ 0.3).

**Table 16. Factor correlation matrix for the oblique three-factor solution (item analysis regarding smart grid acceptance)**

| Factor | 1 | 2 | 3 |
|---|---|---|---|
| 1 | 1.000 | -.396 | .446 |
| 2 | -.396 | 1.000 | -.318 |
| 3 | .446 | -.318 | 1.000 |

**Table 17. KMO and Bartlett's test of sphericity (test statistics for items regarding smart grid acceptance)**

| | | |
|---|---|---|
| Kaiser-Meyer-Olkin Measure of Sampling Adequacy. | | .814 |
| Bartlett's Test of Sphericity | Approx. Chi-Square | 407.692 |
| | df | 15 |
| | Sig. | .000 |

The result of KMO and Bartlett's test of sphericity are shown in Table 17. The value of Kaiser-Meyer-Olkin measure of sampling adequacy is .814 and the Bartlett's test of sphericity is ($p < .001$), which indicates the sample data are suitable for a factor analysis to proceed.

Communalities after extraction varied from 0.688 (item 2) to 0.888 (item 6). Table 18 provides the factor analysis result, and loadings < .30 are not displayed in the table. Although based on theory construction, there should be four factors to be studied. However, since the second factor the eigenvalues are smaller than 1. Here it shows the extraction result for three factors. The three factors explained 80.3% of the total variance. As there is only one question item to capture the latent variable "behavioral intention", "perceived norm" and "perceived behavioral control" related to smart grid respectively, the divergence between different factors is not quite clear. And from Table 16 it can be seen that there are correlations among the three factors.

Item 2 and item 4 have high factor loadings on the first factor (Attitude toward smart grid). Item 6 has a high factor loading on the second factor (Perceived behavioral control). Item 5 has a high factor loading on the third factor (Perceived norm). Item 3 has a little higher factor loading on the first factor (Attitude toward smart grid) than the third factor (Perceived norm). As there is only one item representing the construct "Intention to participate in smart grid applications", the factor for behavioral intention could not be abstracted, which leads to item 1 having a higher factor loading on the second factor (Perceived behavioral control). Nevertheless, for item 2 to item 4 which were supposed to measure the latent variable "Attitude toward smart grid", it shows a Cronbach's-α of .715 for the reliability statistics. Before the reliability calculation, item 2 and item 4 with negative expectations were reverse scored. Apart from the intention item (item 1), other items have high loadings on their hypothesized constructs.

**Table 18. Principal component analysis of items regarding smart grid acceptance (direct oblimin rotation)**

| | Factor 1 | Factor 2 | Factor 3 |
|---|---|---|---|
| 1. If my electricity supplier makes it possible for me to participate in smart grid applications, I will be very likely to take part. | | -.550 | .454 |
| 2. Smart grid will not be implemented in Germany. | -.775 | | |
| 3. I support smart grid implementation because it contributes to the sustainable society. | .518 | | .516 |
| 4. I am against smart grid implementation because the costs are too high. | -.885 | | |
| 5. Most of the people who are important to me (e.g., friends/family, neighbors) think that it is good that I support smart grid. | | | .931 |
| 6. I am against smart grid implementation because I need to allow electricity suppliers to control my consumption. | | .946 | |
| Eigenvalue (unrotated) | 3.36 | 0.79 | 0.67 |
| Percentage of variance explained (unrotated*) | 56.0 | 13.2 | 11.1 |

Extraction Method: Principal Component Analysis.

Rotation Method: Oblimin with Kaiser Normalization.

* cannot obtain variance explained after oblique rotation due to correlated factors

### 5.4.3 As "prosumer" using solar cells

In the survey there are 8 items (see Table 20) related to constructs of theory of planned behavior applied in solar cell investment. Five factors (investment behavior, behavioral intention, attitude toward PV, perceived norm, and perceived behavioral control) are supposed to be extracted. The principal component analysis (PCA) with oblique rotation (direct oblimin) was performed using SPSS version 21. It was found that correlations among factors are not substantial. Therefore, the results of PCA with orthogonal rotation (varimax rotation) as extraction method are reported below.

**Table 19. KMO and Bartlett's test of sphericity (test statistics for items regarding solar cell investment)**

| | | |
|---|---|---|
| Kaiser-Meyer-Olkin Measure of Sampling Adequacy. | | .806 |
| Bartlett's Test of Sphericity | Approx. Chi-Square | 615.862 |
| | df | 28 |
| | Sig. | .000 |

The result of KMO and Bartlett's test of sphericity are shown in Table 19. The value of Kaiser-Meyer-Olkin measure of sampling adequacy is .806 and the Bartlett's test of sphericity is ($p < .001$), which indicates the sample data are suitable for a factor analysis to proceed.

Communalities after extraction varied from 0.606 (item 7) to 0.899 (item 8). Table 20 shows the factor analysis result, and loadings < .30 are not displayed in the table. Although based on theory construction, there should be five factors to be studied. However, since the third factor the eigenvalues are smaller than 1. Here it shows the extraction result for four factors. The four factors explained 74.9% of the total variance.

As there is only one item to capture the latent variable "behavior", "behavioral intention", "perceived norm" and "perceived behavioral control" related to solar cells respectively, the divergence between factor 1 and factor 2 is not quite clear. Item 7 has a higher factor loading on the first factor (Perceived norm). Item 3, item 4 and item 6 have higher factor loadings on the second factor (Attitude toward home PV). Item 1[17] has a high factor loading on the third factor (Investment behavior). Item 8 has a high factor loading on the fourth factor (Perceived behavioral control). Surprisingly, item 5 only has a high factor loading on the first factor (Perceived norm) instead of the second

[17] The question was designed this way, due to consideration of citizens as renters, even if it is not possible for them to install PV on the roof, they could invest in collective solar parks, community shared solar energy projects etc.

factor (Attitude toward home PV). As there is only one imaginary question item measuring the latent variable "Intention to install PV on the roof", the factor for behavior intention could not be abstracted, which leads to item 2 having a higher factor loading on the first factor (Perceived norm) and have factor loadings on the second and third factor as well. Nevertheless, for item 3 to item 6 which were supposed to represent the latent variable "Attitude toward home photovoltaics"[18], it shows a Cronbach's-α of .704 for the reliability statistics. Deleting item 5 will compromise the Cronbach's-α value. Before the reliability calculation, item 3 and item 4 with negative expectations were reverse scored. Apart from measured items on attitude and behavioral intention, other measured items have high loadings on their hypothesized constructs.

[18] Factor analysis of all V39 items (opinions about home PV, see Appendix) show that V39f (intensive maintenance) and V39g (independence from electricity supplier) belong to a different category. After deleting them, the value of Cronbach's-α did not change. V39e (reliability) was not included here due to relatively high portion of missing values and for this item a number of people cannot make their evaluations yet. V39c (appearance) was not included here because more than 80% of respondents do not feel PV looks ugly, which indicates using this item would not be very helpful to differentiate consumers.

**Table 20. Principal component analysis of items regarding solar cell investment (varimax rotation)**

| | Factor 1 | Factor 2 | Factor 3 | Factor 4 |
|---|---|---|---|---|
| 1. I/My family have/has invested in solar cells. | | | .896 | |
| 2. If possible, I can imagine having a rooftop solar system installed. | .625 | -.316 | .302 | |
| 3. I think it is very expensive to apply home photovoltaics for electricity generation. | | .867 | | |
| 4. I think it harms the environment to apply home photovoltaics for electricity generation. | -.423 | .646 | | |
| 5. I think applying home photovoltaics for electricity generation is modern. | .874 | | | |
| 6. I think it is worthwhile to invest in home photovoltaics for electricity generation. | .475 | -.582 | | |
| 7. Most of the people who are important to me (e.g., friends/family, neighbors) think that it is good that I install a PV system. | .675 | -.370 | | |
| 8. I have been often informed about home installations of renewable energies. | | | | .919 |
| Eigenvalue (unrotated values in parentheses) | 2.07 (3.17) | 1.77 (1.29) | 1.09 (0.78) | 1.06 (0.74) |
| Percentage of variance explained (unrotated values in parentheses) | 25.8 (39.7) | 22.1 (16.2) | 13.7 (9.7) | 13.3 (9.3) |

Extraction Method: Principal Component Analysis.

# 6. Structural equation modeling (SEM)

## 6.1 Introduction

Many abstract concepts that are of interest in psychological or social research are very difficult to be directly measured. Those latent constructs which cannot be measured directly can be represented by indicators that are observable (Byrne, 1998, p4).

Structural equation modeling (SEM) is a quantitative statistical method which allows researchers to study relationships among latent constructs. Beyond that, this multivariate approach can examine a series of interrelated relationships among dependent and independent constructs simultaneously, by combining aspects of path analysis, multiple regression and factor analysis (Schumacker and Lomax, 1996; Hair et al, 2006). It also integrates other techniques like (M)ANOVA, analysis of covariance and many others (Nachtigall et al, 2003).

Typically, a structural equation model has a measurement model that defines relations between the latent constructs and their indicators/manifest variables[19], and a structural model which tests relationships among different latent factors. One advantage of using SEM is that the measurement model can be evaluated by using confirmatory factor analysis (CFA) (Kline, 2005). Moreover, data analysis using SEM can incorporate both unobserved and observed variables, and SEM offers explicit estimates of error terms for each variable. Therefore, a hypothesized model can be tested in a simultaneous analysis with all variables in the entire system. As SEM is more comprehensive and flexible, it has become a common method to represent dependency relations in behavioral and social sciences (Hoyle, 1995; McDonald and Ringo Ho, 2002).

The fit between the hypothesized model and the empirical data in SEM is determined by goodness-of-fit indices such as chi-square, CFI (comparative fit index), RMSEA (root mean square error of approximation), and SRMR (standardized root mean square residuals) along with the parameter estimates. A good fit suggests that hypothesized relations among variables are plausible, or else modifications are needed.

[19] Manifest variables are often items of a questionnaire, but can be any type of measured data.

The smaller chi-square is, the better the model fits. The chi-square ($x^2$) is reported with the number of degrees of freedom associated with the model, and a significance test. The degree of freedom (*df*) is a function of the number of covariances provided and the number of paths specified. A non-significant value ($p > 0.05$) is desirable which means that the data do not depart significantly from the model. But the chi-square is sensitive to sample size and it is also acceptable if $1.0 < x^2/df < 3.0$ (Carmnines and McIver, 1981; Thacker et al, 1989). To represent a good model fit, the recommended threshold for CFI is 0.90 (0.95 or higher is better), and for SRMR less than 0.08 is considered as good fit. For RMSEA less than 0.08 indicates reasonable fit, and from 0.08 to 0.10 indicates mediocre fit (Bollen, 1989; Hu and Bentler, 1999).

## 6.2 Analysis results

**Research question 2: Which factors influence these different individual behaviors? And to what extent?**

### 6.2.1 Electricity saving behavior

The theoretical constructs (SB, ATS, PN1, PBC1) from TPB were operationalized using items as shown in Table 21.

**Table 21. Constructs and variables for the model of electricity saving behavior**

| Construct | Item | |
|---|---|---|
| Saving (electricity) behavior (**SB**) | **sb1** | I usually remember to turn lights off when I leave the room. |
| | **sb2** | Usually when I do not use my computer for a long time, I will shut it down. |
| | **sb3** | When I do not use an appliance for a long time, I will shut it completely down. |
| | **sb4** | I pay much attention to whenever possible I could save electricity at home. |
| Attitude toward saving own electricity (**ATS**) | **ats1** | Although big companies consume much electricity, myself saving electricity is still meaningful. |
| | **ats2** | No matter how much or little I consume the electricity, it still makes a difference for the environment. |

| | | |
|---|---|---|
| Perceived norm (**PN1**) | **pn1** | Most of the people who are important to me (e.g., friends/family, neighbors) think that I should save electricity. |
| Perceived behavioral control (**PBC1**) | **pbc1** | More information about my consumption cannot help me consume less electricity. (It indicates I have enough information that I need.) |

**Table 22. Statistics of items regarding electricity saving in the survey sample**

| Item | N | Mean | Standard Deviation | Skewness | Kurtosis | Missing |
|---|---|---|---|---|---|---|
| **sb1 =V7a** | 516 | 1.61 | 0.790 | 1.296 | 1.498 | 0.2% |
| **sb2 =V7b(reversed)** | 515 | 2.29 | 1.196 | .595 | -.685 | 0.4% |
| **sb3 =V7d(reversed)** | 511 | 2.23 | 1.252 | .748 | -.550 | 1.2% |
| **sb4 =V7e** | 514 | 2.08 | 0.971 | .693 | -.067 | 0.6% |
| **ats1=V8a(reversed)** | 511 | 1.56 | 0.916 | 1.859 | 3.217 | 1.2% |
| **ats2=V8b(reversed)** | 509 | 2.12 | 1.283 | .956 | -.264 | 1.5% |
| **pn1=V8c** | 375 | 2.27 | 0.976 | .786 | .498 | 27.5% |
| **pbc1=V8e(reversed)** | 490 | 2.85 | 1.310 | .060 | -1.215 | 5.2% |

Mean and standard deviation of each item were listed in Table 22. Skewness values of items ranged from 0.060 to 1.859. Kurtosis values of items ranged from -1.215 to 3.217. Variables with absolute values of skewness index greater than 3, or with absolute values of kurtosis index greater than 8 suggest non-normality problem (Kline, 2005, p63). Therefore, the range of skewness and kurtosis values here did not indicate severe non-normal data. From the table it can be seen that most items do not exceed 6% of missing values. Only the item (pn1) measuring the perceived norm reports a high portion of missing values, which indicates that a certain amount of citizens are not aware of how their friends or neighbors think about saving electricity.

Except item pn1, other percentages of missing values for question items are acceptable. Then the randomness of missing data for pn1 was investigated. The results of Little's MCAR test suggest that the test is not significant (*Chi-Square* = 45.721, *df* = 40, *p* = .247). The missing values of perceived norm are found to be randomly distributed over gender, age, education and income groups. And the pattern of missing values does not depend on the data values. Therefore, it seems reasonable to assume that the missing data is

Missing Completely at Random and listwise delete cases with missing values. A sample of 348 German citizens was used to analyze electricity saving behavior.

**Structural equation modeling analysis**

Structural equation modeling (SEM) software EQS version 6.1 was used to explore statistical relationships between measured items of each factor and among the factors of independent variables (i.e., ATS, PN1, PBC1) and the dependent variable (i.e., SB).

A confirmatory factor analysis (CFA) was conducted first. In the CFA, by using the maximum likelihood (ML) estimation method the measurement model was tested, i.e. the relationships between the manifest variables and latent factors, and all latent factors/constructs are allowed to covary as shown in Figure 5. Figure 6 shows the factor loadings of the manifest variables on their latent constructs. Question items with negative expectations were reverse scored (see Table 22) before performing CFA. For the constructs of PN1 and PBC1, as there is only one item represents each, it is not possible to estimate measurement errors of items pn1 and pbc1.

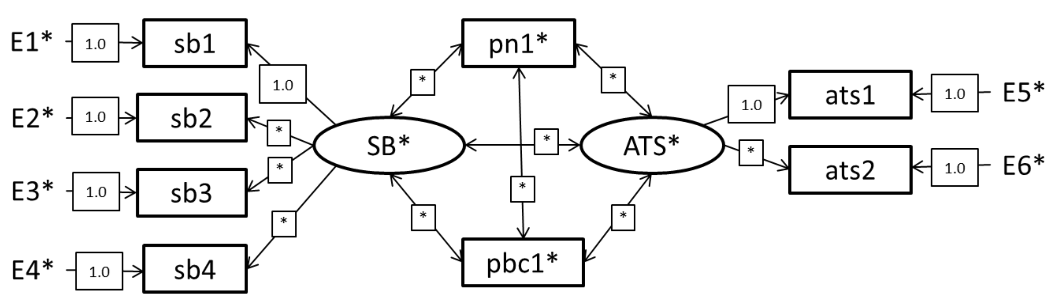



**Figure 5. Hypothesized CFA model for electricity saving**

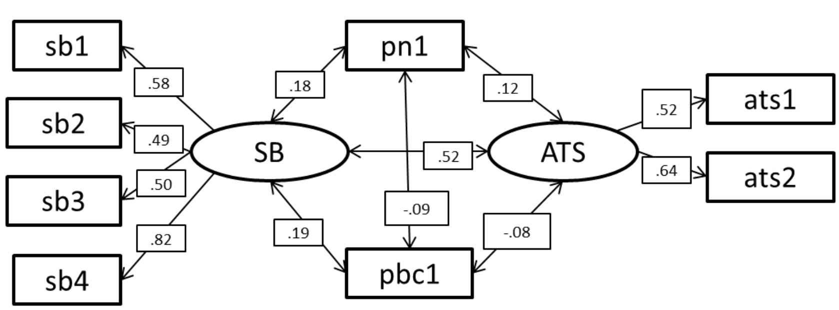



**Figure 6. Standardized solutions of the CFA model for electricity saving**

Indicator loadings on constructs were all significant at $P < .05$. Except paths (the path between pn1 and pbc1, the path between ATS and pn1, and the path between ATS and pbc1) other paths were found to be statistically significant. Variable sb4 has the highest factor loadings on the construct SB. Variable ats2 has relative higher factor loadings on the construct ATS compared to ats1. Variable sb2 and variable sb3 have factor loadings around 0.5 on the construct SB, however, deleting them will compromise the Cronbach's-α value. Reliability and validity of the measurement model were also assessed. Results of composite reliability (CR) and average variance extracted (AVE) do not show severe problems of constructs SB and ATS.

Several model fit indices such as model chi-square, Comparative Fit Index (CFI), Root Mean Square Error of Approximation (RMSEA), and Standardized Root Mean Square Residual (SRMR) were inspected to examine the fit of the measurement model. The chi-square value was significant $x^2 = 55.153$, $df = 16$, $p = .00$, which indicates that the measurement model was rejected. Other fit indices are: RMSEA = .084; CFI = .890; SRMR= .055. Based on modification indexes[20], with the inclusion of the one error covariance between Item sb2 and Item sb3, an adequate fit model (RMSEA = .052; CFI = .960; SRMR= .046) was obtained. The chi-square value for this model was still significant $x^2 = 29.263$, $df = 15$, $p < .05$. Item sb2 asks if the citizen shuts down the computer when not using it for a long time. Item sb3 asks if the citizen chooses to shut down electric appliances completely when not using them for a long time. It makes sense that content overlap generates the error covariance.

Correlations between SB and ATS, between SB and pn1, between SB and pbc1 are positive and significant. Overall, the relationships were consistent with the theoretical model and support proceeding to analyze the structural model.

[20] The modification index is a tool to help improve the model fitting to the data.

## Hypothesis testing

This section presents results of relationship examination among latent constructs. The questionnaire was designed based on the theory of planned behavior (TPB), though there is no measurement on intention of saving electricity but directly on saving behavior (SB). The survey aims to test a model of electricity saving behavior (SB), which is hypothesized to be affected by three main factors, which include attitude toward saving own electricity (ATS), perceived norm (PN1) and perceived behavioral control (PBC1). Figure 7 shows three hypotheses represented by causal paths (H1, H2, H3) based on the theoretical model, which will be used to test the structural model.

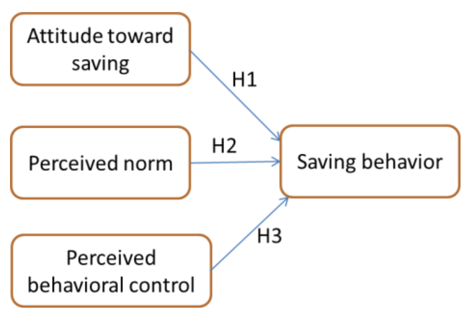



**Figure 7. Proposed hypotheses in the model of electricity saving behavior**

**H1:** Attitude toward saving own electricity (ATS) has a positive effect on electricity saving behavior (SB).
**H2:** Perceived norm (PN1) has a positive effect on electricity saving behavior (SB).
**H3:** Perceived behavioral control (PBC1) has a positive effect on electricity saving behavior (SB).

Goodness-of-fit indices show this hypothesized structural model fits the data well (RMSEA = .053; CFI = .951; SRMR= .051). The chi-square value for this model was significant $x^2$ = 35.298, $df$ = 18, $p$ < .01, but the $x^2/df$ =1.961 was within the threshold level (i.e., $1.0 < x^2/df < 3.0$) also representing that this model fits the data well.

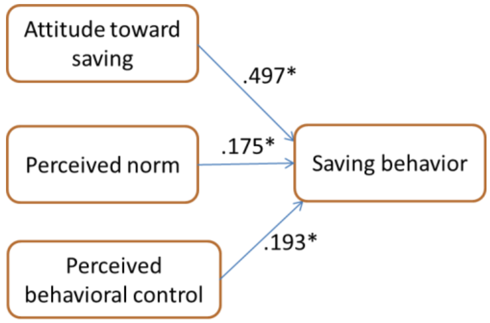



**Figure 8. Standard solutions of the structural model of electricity saving behavior, *p < .05**

As shown in Figure 8, the three direct paths show statistically significant effects and path coefficients are all positive, thus all the three hypotheses (H1, H2, H3) were corroborated as shown in Table 23.

**Table 23. Hypotheses testing for electricity saving behavior**

| Construct | Code | Hypotheses | Hypothesized Relationships | Supported |
|---|---|---|---|---|
| Attitude toward saving own electricity | ATS | H1 | ATS → SB | Yes |
| Perceived norm | PN1 | H2 | PN1 → SB | Yes |
| Perceived behavioral control | PBC1 | H3 | PBC1 → SB | Yes |

This model explained statistically significant amount of variance for each latent variable. And the value of $R^2$ coefficient shows that the overall model explained 32% of the variance in the data, which indicates the predictive power of the electricity saving behavior model.

The effects of attitude towards saving own electricity, perceived norm and perceived control on the behavior of saving electricity are all supported by the data. Standard path coefficients represent the strength of relationships among latent factors (see Figure 8). The higher a path coefficient is, the stronger effect the casual factor has on the dependent variable. Attitude has the biggest effect on saving behavior. This suggests that the more positive attitude citizens hold towards saving electricity, more probably they save electricity. Besides, with no information barrier and with support from important others like friends in saving electricity, then it will be highly likely that citizens perform the behavior of saving electricity.

### 6.2.2 Intention to participate in smart grid applications

The theoretical constructs (ISG, ATSG, PN2, PBC2) from TPB were operationalized using items as shown in Table 24.

**Table 24. Constructs and variables for the model of smart grid acceptance**

| Construct | Item | |
|---|---|---|
| Intention to participate in smart grid applications (**ISG**) | **isg1** | If my electricity supplier makes it possible for me to participate in smart grid applications, I will be very likely to take part. |
| Attitude toward smart grid (**ATSG**) | **atsg1** | Smart grid will be implemented in Germany. |
| | **atsg2** | I support smart grid implementation because it contributes to the sustainable society. |
| | **atsg3** | I will support the application of smart grid, if the costs are not high. |
| Perceived norm (**PN2**) | **pn2** | Most of the people who are important to me (e.g., friends/family, neighbors) think that it is good that I support smart grid. |
| Perceived behavioral control (**PBC2**) | **pbc2** | I will support the application of smart grid, if I didn't feel my consumption controlled by the electricity supplier. |

**Table 25. Statistics of items regarding smart grid acceptance in the survey sample**

| Item | N | Mean | Standard Deviation | Skewness | Kurtosis | Missing |
|---|---|---|---|---|---|---|
| **isg1 =V12c** | 434 | 2.25 | 1.202 | .933 | -.005 | 16.1% |
| **atsg1=V12b(reversed)** | 336 | 2.51 | 1.031 | .305 | -.570 | 35.0% |
| **atsg2=V12e** | 392 | 2.34 | 1.129 | .789 | .058 | 24.2% |
| **atsg3=V12f(reversed)** | 356 | 2.00 | 1.035 | 1.090 | .835 | 31.1% |
| **pn2=V12d** | 219 | 2.45 | 0.996 | .779 | .728 | 57.6% |
| **pbc2=V12g(reversed)** | 400 | 2.35 | 1.172 | .644 | -.401 | 22.6% |

Mean and standard deviation of each item were listed in Table 25. Skewness values of items ranged from 0.305 to 1.090. Kurtosis values of items ranged from -0.570 to 0.835. Variables with absolute values of skewness index greater than 3, or with absolute values of kurtosis index greater than 8 suggest non-normality problem. Therefore, the range of skewness and kurtosis values here did not indicate severe non-normal data. From the table it can be seen that all items exceed 10% of missing values. And the item (pn2) measuring the perceived norm reports the highest portion of missing values, which indicates that a great amount of citizens are not aware of how their friends or neighbors think about smart grid.

The randomness of missing data was investigated. The results of Little's MCAR test suggest that the test is significant (*Chi-Square* = 139.494, *df* = 109, *p* = .026). Because the significance value is less than 0.05, it can be concluded that the data are not missing completely at random.

Results of separate-variance t tests show that the missing values of pn2 depend on the value of variable isg1. Besides, it turns out that female respondents are more likely to have missing values than the average sample; younger respondents (< 40 years old) are more likely to have missing values than the average sample; respondents with lower income (< 1500 Euro) are more likely to have missing values than the average sample. Then parameter estimates based on listwise deletion could be biased. Multiple imputations with Expectation-Maximization (EM) algorithm and Monte Carlo Markov chain (MCMC) method in missing data imputation were tried. But for SEM results there are no substantial differences between cases with imputed values and cases without imputations in:

-whether indicator loadings on constructs are significant or not.
-factors with the highest and lowest loadings on constructs keep the same.

The crucial difference is that perceived norm will have greater influence on the intention to participate in smart grid applications in imputed cases. But the missing rate of question item pn2 is too high. Imputed cases could still generate biased parameter estimates. Therefore, the analysis for the sample of 173 German citizens without imputations will be described below.

**Structural equation modeling analysis**

Structural equation modeling (SEM) software EQS version 6.1 was used to explore statistical relationships between measured items of each factor and among the factors of independent variables (i.e., ATSG, PN2, PBC2) and the dependent variable (i.e., ISG).

A confirmatory factor analysis (CFA) was conducted first. In the CFA, by using the maximum likelihood (ML) estimation method the measurement model was tested, i.e. the relationships between the manifest variables and latent factors, and all latent factors/constructs are allowed to covary as shown in Figure 9. Figure 10 shows the factor loadings of the manifest variables on their latent constructs. Question items with negative expectations were reverse scored (see Table 25) before performing CFA. For the constructs of ISG, PN2 and PBC2, as there is only one item represents each, it is not possible to estimate measurement errors of items isg1, pn2 and pbc2.

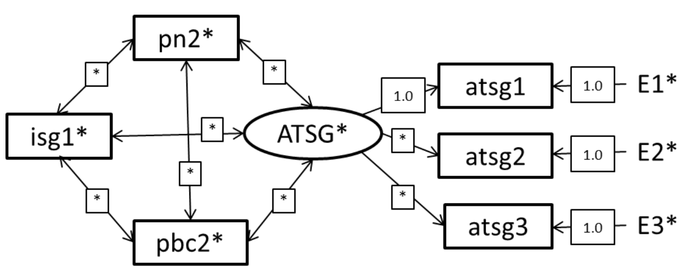



**Figure 9. Hypothesized CFA model for smart grid acceptance**

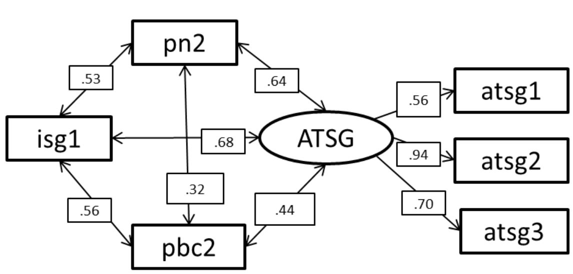



**Figure 10. Standardized solutions of the CFA model for smart grid acceptance**

Indicator loadings on constructs were all significant at P < .05. All the paths were found to be statistically significant as well. Variable atsg2 has the highest factor loading on the construct ATSG. Reliability and validity of the measurement model were also assessed. Results of composite reliability (CR) and average variance extracted (AVE) confirm the construct ATSG was well represented.

To examine the fit of the measurement model, the chi-square value shows significant result: $x^2 = 13.649$, $df = 6$, $p < .05$. But other fit indices suggested that the measurement model fits the data well (RMSEA = .086; CFI = .981; SRMR= .038).

Correlations between isg1 and ATSG, between isg1 and pn2, between isg1 and pbc2 are positive and significant. Overall, the relationships were consistent with the theoretical model and support proceeding to analyze the structural model. In addition, there are significant correlations between pn2 and pbc2, between ATSG and pn2, between ATSG and pbc2.

**Hypothesis testing**

This section presents results of relationship examination among latent constructs. The questionnaire was designed based on the TPB theory, yet there is only measurement on intention to participate in smart grid applications but no measurement on behavior. The survey aims to test a model of intention to participate in smart grid applications (ISG), which is hypothesized to be affected by three main factors, which include attitude toward smart grid (ATSG), perceived norm (PN2) and perceived behavioral control (PBC2). Figure 11 shows three hypotheses represented by causal paths (H4, H5, H6) based on the theoretical model, and additional two correlations from CFA results were presumed as paths (H7, H8), which will be used to test the structural model.

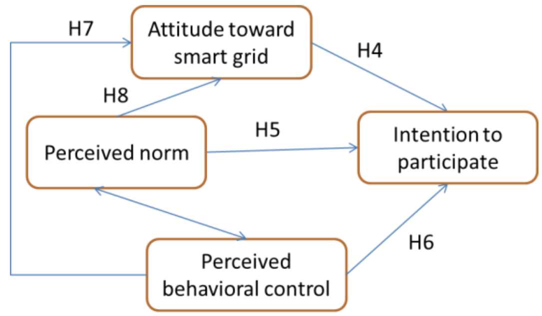



**Figure 11. Proposed hypotheses in the model of intention to participate in smart grid applications**

**H4:** Attitude toward smart grid (ATSG) has a positive influence on intention to participate in smart grid applications (ISG).
**H5:** Perceived norm (PN2) has a positive influence on intention to participate in smart grid applications (ISG).
**H6:** Perceived behavioral control (PBC2) has a positive influence on intention to participate in smart grid applications (ISG).
**H7:** Perceived behavioral control (PBC2) has a positive influence on attitude toward smart grid (ATSG).
**H8:** Perceived norm (PN2) has a positive influence on attitude toward smart grid (ATSG).

Goodness-of-fit indices show this hypothesized structural model provided the same fit to the data, although the chi-square value was significant: $x^2 = 13.649$, $df = 6$, $p < .05$. Other fit indices (RMSEA = .086; CFI = .981; SRMR= .038) keeps the same as the measurement model. All paths but the path (PN2 $\rightarrow$ ISG) show statistically significant effects and path coefficients are all positive. Therefore all the three hypotheses but H5 were corroborated as shown in Table 26.

**Table 26. Hypotheses testing for intention to participate in smart grid applications**

| Construct | Code | Hypotheses | Hypothesized Relationships | Supported |
|---|---|---|---|---|
| Attitude toward smart grid | ATSG | H4 | ATSG $\rightarrow$ ISG | Yes |
| Perceived norm | PN2 | H5 | PN2 $\rightarrow$ ISG | No |
| | | H8 | PN2 $\rightarrow$ ATSG | Yes |
| Perceived behavioral control | PBC2 | H6 | PBC2 $\rightarrow$ ISG | Yes |
| | | H7 | PBC2 $\rightarrow$ ATSG | Yes |

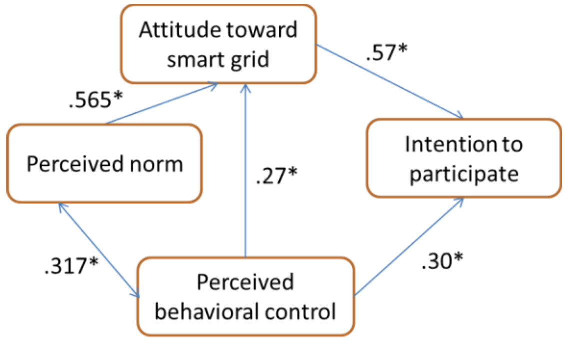



**Figure 12. Standard solutions of modified structural model of intention to participate in smart grid applications, *p < .05**

After deleting the path (PN2 → ISG), an adequate fit model (RMSEA = .092; CFI = .975; SRMR= .039) was obtained as shown in Figure 12. Because people have low level of knowledge on smart grid, then they are supposed to have much less knowledge about how their friends or neighbors think about smart grid, which explains pn2 has a large portion of missing values and negligible effect of the path (PN2 → ISG). In addition to goodness-of-fit statistics above, the chi-square value for this model was significant $x^2$ = 17.180, $df$ = 7, $p$ < .05, but the $x^2/df$ =2.454 was within the threshold level (i.e., 1.0 < $x^2/df$ < 3.0) also representing that this modified model fits the data well. The model explained statistically significant amount of variance for each latent variable. And the value of $R^2$ coefficient shows that the overall model explained 56% of the variance in the data, which indicates the predictive power of smart grid acceptance model.

The effects of attitude towards smart grid and perceived control on the intention to participate in smart grid applications are supported by the data. Perceived norm do not have a direct influence on the intention, instead, as social influence contributing to citizens' attitudes toward smart grid. Maybe owing to too many unknowns from respondents about smart grid, perceived behavioral control (PBC2) has more ways to affect than expected: PBC2 has a positive influence on attitude toward smart grid and has correlations with perceived norm.

Standard path coefficients represent the strength of relationships among latent factors (see Figure 12). The higher a path coefficient is, the stronger effect the casual factor has on the dependent variable. Attitude has the biggest effect on the intention. This suggests that the more positive attitude citizens hold towards smart grid, with higher probability people tend to participate in smart grid applications. Besides, no threat of feeling controlled in electricity consumption (directly and indirectly) and with support from important others like friends in smart grid (indirectly), will help increase citizens' willingness to participate in smart grid applications.

### 6.2.3 As "prosumer" using solar cells

The theoretical constructs (IB, IIPV, ATPV, PN3, PBC3) from TPB were operationalized using items as shown in Table 27.

**Table 27. Constructs and variables for the model of investment behavior in solar cells**

| Construct | Item | |
|---|---|---|
| Investment behavior (**IB**) | **ib1** | I/My family have/has invested in solar cells. |
| Intention to install PV on the roof (**IIPV**) | **iipv1** | If possible, I can imagine having a rooftop solar system installed. |
| Attitude toward home photovoltaics[21] (**ATPV**) | **atpv1** | I think it is not expensive to apply home photovoltaics for electricity generation. |
| | **atpv2** | I think it benefits the environment to apply home photovoltaics for electricity generation. |
| | **atpv3** | I think applying home photovoltaics for electricity generation is modern. |
| | **atpv4** | I think it is worthwhile to invest in home photovoltaics for electricity generation. |
| Perceived norm (**PN3**) | **pn3** | Most of the people who are important to me (e.g., friends/family, neighbors) think that it is good that I install a PV system. |
| Perceived behavioral control (**PBC3**) | **pbc3** | I have been often informed about home installations of renewable energies. |

[21] Factor analysis of all V39 items show that V39f and V39g belong to a different category. After deleting them, the value of Cronbach's-α did not change. V39e was not included here due to relatively high portion of missing values and regarding the item a number of people cannot make their evaluations yet. V39c was not included here because more than 80% of respondents do not feel PV looks ugly, which indicates using this item would not be very helpful to differentiate consumers.

**Table 28. Statistics of items regarding solar cell investment in the survey sample**

| Item | N | Mean | Standard Deviation | Skewness | Kurtosis | Missing |
|---|---|---|---|---|---|---|
| **ib1=V36c** | 502 | 1.71 | 0.456 | -.903 | -1.190 | 2.9% |
| **iipv1=V38** | 499 | 1.31 | 0.588 | 1.770 | 2.000 | 3.5% |
| **atpv1=V39a(reversed)** | 456 | 2.51 | 1.226 | .409 | -.917 | 11.8% |
| **atpv2=V39b(reversed)** | 473 | 1.78 | 0.999 | 1.322 | 1.248 | 8.5% |
| **atpv3=V39d** | 454 | 2.09 | 1.057 | 1.046 | .742 | 12.2% |
| **atpv4=V39h** | 464 | 2.17 | 1.121 | .915 | .195 | 10.3% |
| **pn3=V42b** | 395 | 2.02 | 0.922 | 1.069 | 1.360 | 23.6% |
| **pbc3=V33** | 517 | 3.33 | 1.583 | -.282 | -1.471 | 0.0% |

Mean and standard deviation of each item were listed in Table 28. Skewness values of items ranged from -0.903 to 1.770. Kurtosis values of items ranged from -1.471 to 2.000. Variables with absolute values of skewness index greater than 3, or with absolute values of kurtosis index greater than 8 suggest non-normality problem. Therefore, the range of skewness and kurtosis values here did not indicate severe non-normal data. From the table it can be seen that most items have around 10% of missing values. Only the item (pn3) measuring the perceived norm reports the highest portion of missing values, which indicates that a certain amount of citizens are not aware of how their friends or neighbors think about installing a solar panel.

Percentages of missing values for question items ib1, iipv1 and pbc3 are acceptable. Then the randomness of missing data for other variables was investigated. The results of Little's MCAR test suggest that for variable atpv1 the test is not significant (*Chi-Square* = 49.279, *df* = 37, *p* = .085). The results of Little's MCAR test suggest that for variable atpv2 the test is not significant (*Chi-Square* = 40.006, *df* = 36, *p* = .297). The results of Little's MCAR test suggest that for variable atpv3 the test is not significant (*Chi-Square* = 37.613, *df* = 35, *p* = .350). The results of Little's MCAR test suggest that for variable atpv4 the test is not significant (*Chi-Square* = 45.380, *df* = 34, *p* = .092). The results of Little's MCAR test suggest that for variable pn3 the test is not significant (*Chi-Square =* 43.892*, df =* 38*, p =* .236).

The missing values are found to be randomly distributed over gender, age, education and income groups. And the pattern of missing values does not depend on the data values. Therefore, it seems reasonable to assume that the missing data is Missing Completely at Random and listwise delete cases with missing values. A sample of 325 German citizens was used to analyze investment behavior in solar cells.

**Structural equation modeling analysis**

Structural equation modeling (SEM) software EQS version 6.1 was used to explore statistical relationships between measured items of each factor and among the factors of independent variables (e.g., ATPV, PN3, PBC3) and the dependent variable (e.g., IB).

A confirmatory factor analysis (CFA) was conducted first. In the CFA, by using the maximum likelihood (ML) estimation method the measurement model was tested, i.e. the relationships between the manifest variables and latent factors, and all latent factors/constructs are allowed to covary as shown in Figure 13. Figure 14 shows the factor loadings of the manifest variables on their latent constructs. Question items with negative expectations were reverse scored (see Table 28) before performing CFA. For the constructs of IB, IIPV, PN3 and PBC3, as there is only one item represents each, it is not possible to estimate measurement errors of items ib1, iipv1, pn3 and pbc3.

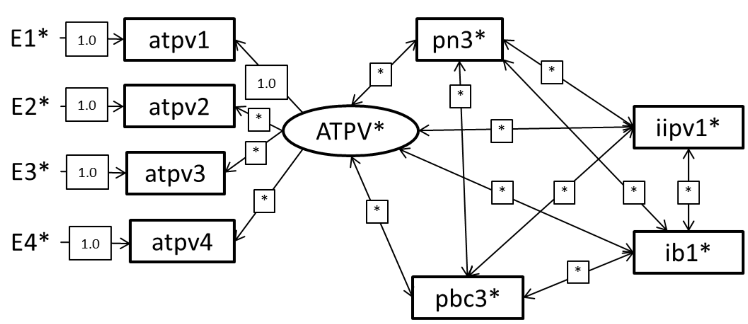



**Figure 13. Hypothesized CFA model for solar cell investment**

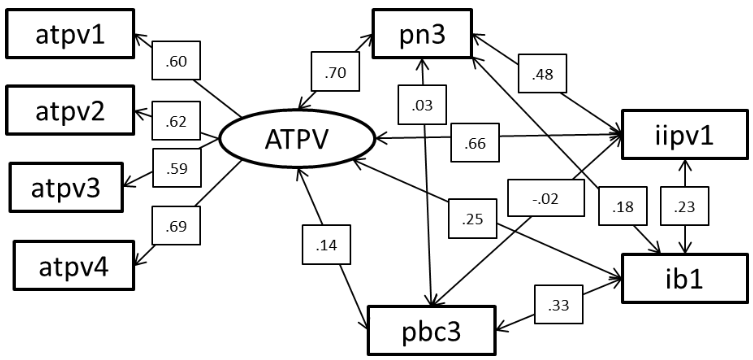



**Figure 14. Standardized solutions of the CFA model for solar cell investment**

Indicator loadings on constructs were all significant at P < .05. Except paths (the path between iipv1 and pbc3, and the path between pbc3 and pn3) other paths were found to be statistically significant. Variable atpv4 has the highest factor loading on the construct ATPV. Reliability and validity of the measurement model were also assessed. Results of composite reliability (CR) and average variance extracted (AVE) do not show severe problems of construct ATPV.

To examine the fit of the measurement model, the chi-square value shows significant result: $x^2 = 46.515$, $df = 14$, $p < .001$. But other fit indices suggested that the measurement model fits the data well (RMSEA = .085; CFI = .945; SRMR= .043). Based on modification indexes, with the inclusion of one cross-loading (atpv1 on PBC3) and one error covariance between Item atpv1 and Item atpv4, an adequate fit model was obtained as shown in Figure 15. Item atpv1 asks how citizen think about the cost due to electricity produced by home PV. Item atpv4 asks if the citizen thinks using home PV to produce electricity is a worthwhile investment. It makes sense that content overlap generates the error covariance. The cost due to electricity produced by PV can be a barrier of the home installation decision, which explains the one cross-loading (atpv1 on PBC3).

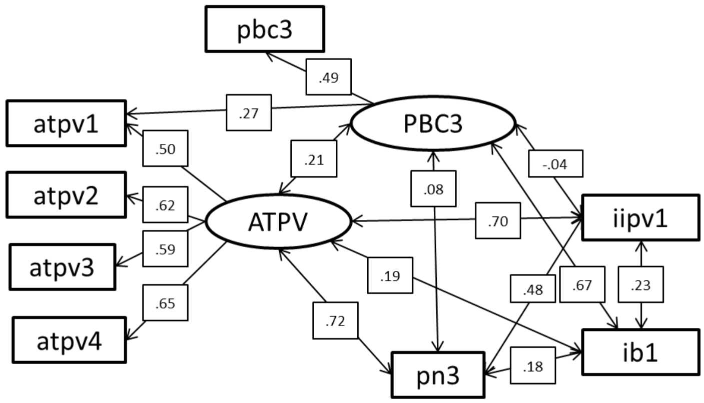



**Figure 15. Standardized solutions of modified CFA model for solar cell investment**

In Figure 15 indicator loadings on constructs were all significant at P < .05. Except paths (the path between iipv1 and PBC3, the path between PBC3 and ATPV, and the path between PBC3 and pn3) other paths were found to be statistically significant. Variable atpv4 still has the highest factor loading on the construct ATPV. Variable pbc3 has a higher factor loading on the construct PBC3. The chi-square value was significant $x^2$ = 20.317, *df* = 11, *p* < .05, but other fit indices suggested that the measurement model fits the data well (RMSEA = .051; CFI = .984; SRMR= .025).

Correlations between iipv1 and ATPV, between iipv1 and pn3, between iipv1 and ib1, between PBC3 and ib1 are positive and significant. iipv1 and PBC3 have non-significant correlation relationships, and one reason is that the imaginary question iipv1 excluding constraints in reality, which could be better designed. Overall, the relationships were consistent with the theoretical model and support proceeding to analyze the structural model. In addition, there are significant correlations between ATPV and ib1, between pn3 and ib1, between ATPV and pn3.

**Hypothesis testing**

This section presents results of relationship examination among latent constructs. The questionnaire was designed based on the TPB theory and it aims to test the model of intention to install PV on the roof (IIPV) and investment behavior in solar cells[22] (IB). IIPV is hypothesized to be affected by three main factors, which include attitude toward home photovoltaics (ATPV), perceived norm (PN3) and perceived behavioral control (PBC3). IB is hypothesized to be affected by two main factors, which include intention to install PV on the roof (IIPV) and perceived behavioral control (PBC3). Figure 16 shows these hypotheses represented by causal paths (H10, H11, H13, H14) based on the theoretical model, and additional three correlations from CFA results were presumed as paths (H9, H12, H15), which will be used to test the structural model.

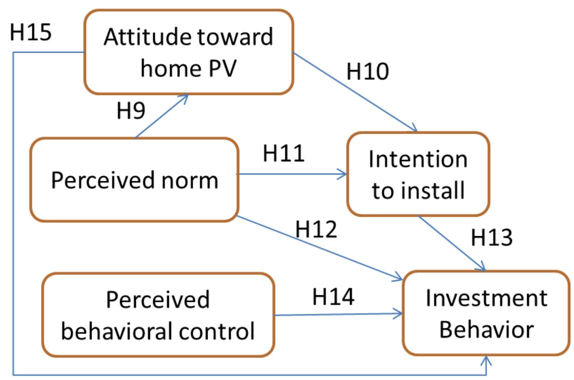



**Figure 16. Proposed hypotheses in the model of investment behavior in solar cells**

**H9:** Perceived norm (PN3) has a positive effect on attitude toward home PV (ATPV).
**H10:** Attitude toward home PV (ATPV) has a positive effect on intention to install PV on the roof (IIPV).
**H11:** Perceived norm (PN3) has a positive influence on intention to install PV on the roof (IIPV).
**H12:** Perceived norm (PN3) has a positive influence on investment behavior in solar cells (IB).
**H13:** Intention to install PV on the roof (IIPV) has a positive influence on investment behavior in solar cells (IB).
**H14:** Perceived behavioral control (PBC3) has a positive influence on investment behavior in solar cells (IB).
**H15:** Attitude toward home PV (ATPV) has a positive influence on investment behavior in solar cells (IB).

Goodness-of-fit indices show this hypothesized structural model provided good fit to the data: RMSEA = .050; CFI = .981; SRMR= .034, the chi-square value was significant though

[22] With consideration of citizens as renters, even if it is not possible for them to install PV on the roof, they could choose other ways to invest in solar cells.

$x^2 = 25.565$, $df = 14$, $p < .05$. All paths but paths (ATPV → IB, PN3 → IB, PN3 → IIPV) show statistically significant effects and path coefficients are all positive. After deleting the three non-significant paths, it provided a better fit model with (RMSEA = .042; CFI = .983; SRMR= .035). The chi-square value for this modified model was not significant $x^2 = 26.868$, $df = 17$, $p = .06$, and the $x^2/df = 1.580$ was within the threshold level (i.e., $1.0 < x^2/df < 3.0$) also representing that this modified model fits the data very well. The model explained statistically significant amount of variance for each latent variable. And the value of $R^2$ coefficient shows that the overall model explained 45% of the variance in the data, which indicates the predictive power of the PV investment model.

Conditions of the hypotheses were shown in Table 29, and only hypotheses 9, 10, 13, and 14 were corroborated. Surprisingly, paths PN3 → IIPV and PBC3 → IIPV were not significant, which is inconsistent with the TPB theory. One reason could be that the imaginary question iipv1 excludes constraints in reality but leaving only mental representation, which should be better designed.

Based on the TPB theory, attitude does not directly affect the behavior, thus no direct path from ATPV to IB is reasonable. The same situation applies to H12: based on the theory perceived norm does not directly impact the behavior, therefore it makes sense that there is no direct path from PN3 to IB.

The effect of attitude towards home PV on the intention to install PV on the roof is supported by the data. The effects of perceived control and intention to install on the investment behavior in solar cells (IB)[23] are also supported by the data. Unfortunately, perhaps due to the poor question design for the intention construct, perceived norm and perceived control have no direct effects on the intention (IIPV).

[23] Respondents were asked whether they have invested in solar cells (item ib1), due to considering citizens as renters, even if it is not possible for them to install PV on the roof, they could invest in collective solar parks, community shared solar energy projects etc.

**Table 29. Hypotheses testing for investment behavior in solar cells**

| Construct | Code | Hypotheses | Hypothesized Relationships | Supported |
|---|---|---|---|---|
| Attitude toward home photovoltaics | ATPV | H10 | ATPV ⟶ IIPV | Yes |
| | | H15 | ATPV ⟶ IB | No |
| Perceived norm | PN3 | H9 | PN3 ⟶ ATPV | Yes |
| | | H11 | PN3 ⟶ IIPV | No |
| | | H12 | PN3 ⟶ IB | No |
| Perceived behavioral control | PBC3 | H14 | PBC3 ⟶ IB | Yes |
| Intention to install PV on the roof | IIPV | H13 | IIPV ⟶ IB | Yes |

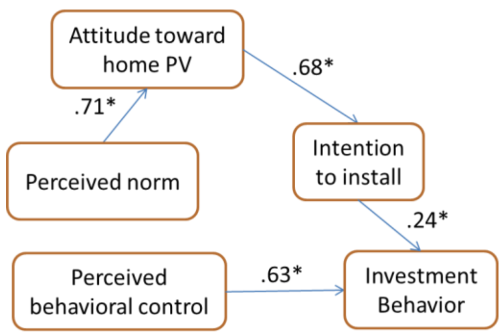



**Figure 17. Standard solutions of modified structural model of investment behavior in solar cells, *p < .05**

Standard path coefficients represent the strength of relationships among latent factors (see Figure 17). The higher a path coefficient is, the stronger effect the casual factor has on the dependent variable. Perceived control has the biggest effect on PV investment behavior. This suggests that the information and cost barriers matter a lot to the investment decision. And the more citizens tend to install a home PV, more probably they make the investment. Besides, citizens' positive attitudes toward photovoltaics (directly on intention, indirectly on investment) and with support from important others like friends in PV installations (indirectly), both will help increase the probability of citizens' investment behavior.

## 6.3 Other factors that influence energy-related practices

**Environmental concerns**

Environmental concern is widely used as a predictor of pro-environmental behaviors (Kaiser et al, 1999). Many studies highlighted the importance of environmental considerations in consumers' choices in energy use as well as acceptance of eco-products (Keirstead, 2007; Valocchi et al, 2009; Ngar-yin Mah et al, 2012). Empirical data from 2047 Dutch households reveals that environmental concern is the most important driver of the intention to generate own electricity (Leenheer et al, 2011). This was also confirmed for PV purchase in UK (Keirstead, 2006). Smart grid projects in Europe often use environmental concern as one motivational factor (Gangale et al, 2013). Kranz and Picot (2012) found environmental concerns significantly impact intention to adopt the smart metering technology. Public support for renewable energy technologies is also found to be motivated by the goal of environmental protection or climate change mitigation (Poortinga et al, 2006). Bamberg (2003) found that social norms have greater influence on behaviors[24] of individuals with low levels of environmental concern whereas control-related factors are more important for those with high levels of concern.

General environmental attitudes—one's evaluation of the relationship between humans and the environment—were not measured in my survey, but specific attitudes regarding the environmental impact associated with behaviors (V8b, V12e, V39b) have been captured. In the three models of target behaviors, contribution to the environment was perceived to be quite an important motive. For consumers who belong to the adoption group regarding electricity saving behavior (see Section 7.2.1) or smart grid participation (see Section 7.2.2) or PV investment (see Section 7.2.3), they all show positive attitudes towards benefiting the environment above average, which is consistent with above-mentioned findings.

[24] In this case, whether participants respond to information about green energy.

**Personal norm**

The influence of personal norms was not studied in this thesis, future research with the addition of personal norms (Norm Activation Model, Schwartz, 1977) is needed. Such feelings of moral obligation were found to be a good predictor of technology acceptance and also contributed to the intention of pro-environmental behaviors (Thøgersen, 1996; Nordlund and Garvill, 2002; Bamberg and Möser, 2007; Biel and Thøgersen, 2007; Harland et al, 2007; De Groot and Steg, 2010; Jansson et al, 2011). Adding personal norms to home energy use and energy savings was found to significantly increase the predictive power in explaining energy savings (Abrahamse and Steg, 2009). But the influence of attitude on the behavioral intention might decrease after the addition of personal norm in the model (Harland et al, 1999). Toft et al (2014) found that attitude together with personal norm accounts for 63% (Denmark), 78% (Norway) and 64% (Switzerland) of the variance in acceptance of smart grid technology.

**Trust**

In my survey there is only one question about trust issue. 43.6% of the respondents (N = 489) highly trust their electricity providers to handle the consumption data, while 29.7% show little trust (Question V21). The cross-table analysis between question item V21 (trust in electricity providers to handle the consumption data) and item V22 (the degree of agreement that the electricity providers can gather electricity consumption data to help balance supply and demand) indicates that people who have higher trust in their electricity providers, the more probable they will agree their consumption data to be gathered. In this way, the concern about private data protection could discourage consumer engagement in smart grid, for which electricity providers should actively prove that they can be trusted. And central to consumer engagement in the future energy retail market will be consumers feel secure that all market participants respect the confidentiality (EC SGTF, 2010).

For many cases, the trust effect on acceptance is indirect via perceived risks and benefits (Montijn-Dorgelo and Midden, 2008; Huijts et al, 2012). When a technology is relatively unknown to consumers, their trust in the actors responsible for the technology or implementation can largely influence their perceptions and even increase acceptance (Siegrist and Cvetkovich, 2000; Midden and Huijts, 2009; Huijts et al, 2012). For smart grid technologies, some citizens lacked trust in the utility company to control their consumption (Toft and Thøgersen, 2015), which can be a barrier for smart grid implementation. Mutual trust between community members, investors and owners of infrastructure systems (e.g., smart meters, infrastructure of renewables) is crucial for community acceptance and thereby successful deployment (Wolsink, 2012). Therefore, marketing about products or technologies are suggested to be linked with trusted messengers and vendors or contractors with good reputation. Applications or products should secure a certain level of reliability and quality which will not undermine consumer trust (Moss and Cubed, 2008).

# 7. Agent-based modeling

**Research question 3: How much can social norms encourage aggregated behavior changes?**

To identify the social norm effect (e.g., the aggregate level of behavior changes due to conformity) in electricity saving, smart grid involvement and PV investment, agent based modeling (ABM) was used, because it offers an easy option to explicitly model personal interactions that exert social influence and this single effect can be observed in isolation, which is rather difficult for empirical investigations. Different interaction typologies between agents—the way they are connected in the social networks—can be taken into account as well through free adjustments or experiments in agent-based models.

In recent years, agent-based simulation has received increasing attentions in modelling. Agent-based modeling is a powerful technique for the computerized simulation of large-scale complex systems, which offers a paradigm for simulating the actions and interactions of autonomous agents (individual or collective entities such as organizations). Each agent is modeled by attributes and rules of behavior. In a bottom-up way, the components and their individual behavior through agents are represented at the microscopic level, and at the macroscopic level, the aggregated system behavior is as a result of the interactions among the multiple single agents of different kinds which make up the system (Kröger and Zio, 2011, pp129-132).

Agent-based modeling (ABM) has become a popular approach for social sciences because it helps understand the macro outcomes due to interactions of individuals in an easier way. The decision rules of individual agents are explicitly represented. Interactions can also be directly defined and be represented more easily than other approaches. For example, friendships can be modeled by a network of nodes and edges. Moreover, it allows researchers to conduct experiments and experiments can be repeated many times. One can control the parameter of interest and observe the effect due to its change only. One can also allow some variables to vary randomly or their values to satisfy certain kind of distributions. Experiments or interventions in the real society are difficult, maybe ethically undesirable or even impossible sometimes, but one can create simplified representation of reality by agent-based modeling with lower costs and more flexibilities (Gilbert, 2009).

In diffusion research agent-based modeling has also been increasingly used. Usually in agent-based diffusion models, individual consumer is one agent in the model. Consumers' decision making processes and their social interactions are explicitly modeled. The macro consequences in the social system emerge from individual behaviors and their interactions at the micro-level. One important stream of literatures on agent-based models in innovation diffusion is the applications which provide decision support based on empirical data, which increases the explanatory power (Kiesling et al, 2012). Theory of planned behavior is commonly used as the theoretical framework for modeling consumer agents' behaviors in diffusion models (Kaufmann et al, 2009; Schwarz and Ernst, 2009; Zhang and Nuttall, 2011). The initialization of the simulation utilizes empirical data. Take this study for example--the three roles (adopters, non-evaluators, and non-adopters) of consumer agents in the initial system are differentiated by the calculated utility values according to their own values in attitude, perceived behavioral control and perceived norm (TPB constructs) grounded in the empirical survey data. That is to say, each consumer agent is initialized with individual preferences corresponding to his or her response in the online survey. Social networks among agents are simulated. Agent-based models will estimate those aggregated behavior changes brought by the social norm diffused by adopters via interpersonal interactions. Section 7.1 will explain this in more detail.

Many studies using ABM to model consumer adoption behaviors presume if more neighboring agents adopt, normative influence in favor of the behavior in question increases. To simulate this effect of social influence through communication links in the network, it is common to employ one kind of decision rule—a consumer agent adopts a particular behavior or a product or an innovation once a certain proportion of its acquaintances has adopted (Valente and Davis, 1999; DeCanio et al, 2000; Goldenberg et al, 2000; Alkemade and Castaldi, 2005; Deffuant et al, 2005; Delre et al, 2007a; Kaufmann et al, 2009). This threshold approach--Conformity occurs through one consumer's perception of how many others have already adopted--has been described in Section 4.4.

## 7.1 Concept of the models

NetLogo (http://ccl.northwestern.edu/netlogo/) software platform is used for agent-based modeling. Each respondent in the survey is represented as a household agent (517 agents) in the agent-based models. As the empirical survey did not include questions about social contacts of respondents, agents are situated in an artificially generated social network in the agent-based simulations. Most networks especially social networks (e.g., acquaintance and friendship networks, online social networks) were found to follow small-world[25] properties (Amaral et al, 2000; Barabasi, 2003; Baracaldo et al, 2011; Kurahashi and Saito, 2011). Therefore, agents (i.e., household consumers) exchange information and opinions via social networks which exhibit small-world properties. Network effects will be examined by which the opinions of neighboring[26] consumers affect one's change in decisions of adopting a specific behavior, which are interpreted as the influence of social norms.

As shown in Figure 18, agents have their own preferences towards target behaviors (i.e., electricity saving, consumer participation in smart grid applications, and solar panel investment). Individual antecedents of consumer behaviors have been examined based on constructs in theory of planned behavior (research question 2, Chapter 6). But consumers are not isolated. They are embedded in the social system and belong to certain groups such as family and community connected by social networks. Consumers may choose to adopt innovative products or practices through interpersonal communications (Rogers, 1983). Information about innovative technologies or practices (e.g., costs and benefits) evaluated by early adopters spread out in the social networks. Conformity may occur through one consumer's perception of adopter percentage within his or her contacts. Such social influence on potential adopters might lead to a larger

[25] Small-world network will be explained in Section 7.3.1.

[26] Here the neighboring represents not neighbors in geographic proximity, but interpersonal connections in the social networks. The agent-based models here will not construct real geographic dimensions.

spread of the innovative practices than marketing strategies targeting individuals in isolation. After consumer agents interact in the agent-based models of social networks, the aggregate behavior outcomes brought by social influence can be observed and examined.

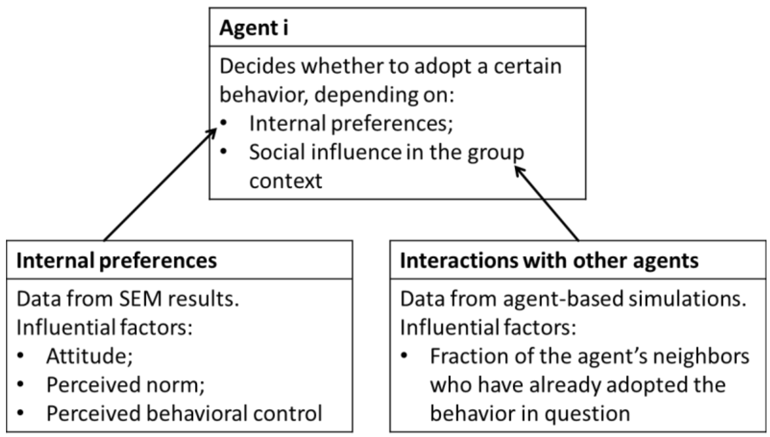



**Figure 18. Agent decision model**

Agent i decides according to a weighted utility[27] of individual preference and social influence on the behavior in question.

$$Utility_i = (Attitude_i \cdot W_{attitude} + Control_i \cdot W_{control}) \cdot (1 - W_{social}) + Social_i \cdot W_{social} \qquad (1)$$

Formula (1) is used to compute the utility value ($Utility_i$) of agent i, which comprises of attitude, perceived behavioral control and perceived norm. Agent-specific values for attitude ($Attitude_i$), perceived norm ($Social_i$) and perceived behavioral control ($Control_i$) are from the empirical survey data. The weights (W) of different decision factors (attitudes, perceived behavioral control and perceived norm) are derived from the standardized regression path coefficient in the structural equation models. Indirect effects were counted as well. After all value scales are transformed in the same defined direction, the utility value ($Utility_i$) of agent i gets higher if it holds higher positive attitude, has more control over the given behavior, and perceives more social desirability. Agent i adopts the behavior when $Utility_i$ is higher than its minimum utility requirement, which is set as 4 in the analysis, consistent with 5-point scales.

[27] For each consumer agent a function of individual utility and social utility has been used in many ABM studies (Schwarz and Ernst, 2009; Choi et al, 2010; Delre et al, 2010; Kiesling et al, 2012).

Following above-mentioned rule to calculate utility value of each respondent/agent, there are already a certain percentage of "adopters" in the sample (see Table 33, Table 37 and Table 41). The diffusion simulation will start from this initial status, as the diffusion begins with the adopters who intentionally disseminate information on innovative technologies or practices in the social networks, through which to positively influence potential adopters and induce the conformity.

At the next time-steps[28], agent i updates the social influence part in formula (1) and calculates the fraction of i's neighbors who have already adopted a certain behavior as social utility[29]. As long as agent i values the social influence (check the $Social_i$ value[30]) and the recalculated utility value ($Utility_i$) of agent i is larger than 4, agent i will be assumed to join the **adopter** group. For those agents that utility values cannot be computed because some respondents have not made a clear evaluation about certain question items for decision factors, they were treated as members of the **non-evaluation** group. If agent i belongs to the non-evaluation group, agent i counts the number of adopters and non-adopters within network contacts. If agent i values the social influence (check the $Social_i$ value) and the adopter group takes an advantage, then agent i will be assumed to join the adopter group. Once agents have adopted a certain behavior, it is assumed that they will not alter their stances as adopter group members. Besides, social utility will not be updated for those agents who do not value social influence (check the $Social_i$ value), as they tend not to search information from contacts about particular behaviors or expectations. Hence their utility values will not be changed, that is to say, agents who do not value social influence will maintain their stances.

[28] Time passes in discrete steps. Each simulation time step has no meaning of real time intervals.
[29] A specific action can be controlled by important others who define the social rightness.
[30] Agents have their own predetermined susceptibility to social influence ($Social_i$, perceived norm question items). If the $Social_i$ value is missing, agents will be treated as prone to social influence, in order to examine the max. changes caused by the normative effect.

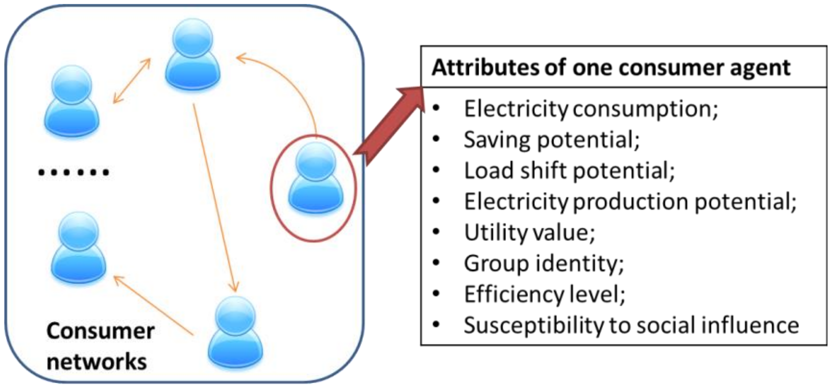



**Figure 19. Attributes of a representative agent in the model**

For each household/consumer agent, yearly electricity consumption was estimated based on the ownership and using frequencies of electric appliances (Questions V3 and V28). The data for specific consumptions of appliances shown in Table 30 referred to (RWI and forsa, 2011; AGEB, 2013; Elsland et al, 2013). In addition, the total consumption of each household went through minor adjustments according to the electricity cost (Question V1c). Electricity used for heating and hot water was not considered here. For the estimated annual electricity consumption of the survey sample, the minimum value is 717 kWh and the maximum is 15 400 kWh, with a mean value of 2819.02 kWh (SD = 1751.184). Table 31 presents the distribution of annual electricity consumption by household size.

**Table 30. Specific consumption of domestic appliances**

| Appliance | Specific consumption of each appliance |
|---|---|
| Refrigerator | 249.9 kWh/year |
| DVD-player | 50.0 kWh/year |
| Computer | 180.7 kWh/year |
| Coffee machine | 86.3 kWh/year |
| Microwave | 33.5 kWh/year |
| Television | 230.7 kWh/year |
| Lighting | 275.9 kWh/year |
| | |
| Washing machine | 0.36 kWh/time of use |
| Dryer | 2.6 kWh/time of use |
| Dishwasher | 2.0 kWh/time of use |
| Electric stove | 0.6 kWh/time of use |
| Baking oven | 0.9 kWh/time of use |

Note: The lifetime of appliances was not considered in the calculation. The prospective development of the ownership rate was not considered as well.

**Table 31. Estimated annual electricity consumption (Unit: kWh) by household size**

| | 1 | 2 | 3 | 4 | >4 |
|---|---|---|---|---|---|
| **Sample size** | 94 | 221 | 81 | 72 | 44 |
| **Mean** | 1653.01 | 2691.19 | 3097.17 | 3565.47 | 4174.80 |
| **SD** | 871.507 | 1572.852 | 1995.878 | 1675.715 | 2079.328 |

## 7.2 Simulation results

As described in Section 7.1, most social networks were found to follow small-world properties. Therefore, agents are embedded in the small-world network[31] generated in NetLogo. Within social networks which exhibit small-world properties, the diffusion of energy practices begins with initial adopters and consumer agents communicate with their contacts. Agents calculate the fraction of their neighbors who have already adopted a certain behavior and then update the social influence part in the decision formula. Conformity may occur due to the presence of prior adopters within personal networks. This part will present aggregate changes (e.g., adoption rate) caused by such effect in one simulation run[32]. The small-world network here used the common network parameters (rewiring-probability = 0.1, k = 4). The influence of network structure on simulation results will be examined in Section 7.3.

### 7.2.1 Electricity saving behavior

Based on the structural equations for the electricity saving behavior, a weighted utility of individual preference and social influence was calculated. The respondents with a utility value of not smaller than 4, belong to the **saving** group. The respondents with a utility value of smaller than 4, belong to the **not-saving** group. For the rest respondents, they have some doubts about certain question items for decision factors, which result in no utility values, and they were treated as members of the **non-evaluation** group.

156 cases belong to the saving group, while 198 cases belong to the not-saving group. For the items of measuring attitude, perceived norm and perceived behavioral control

[31] The NetLogo model is adapted from a model proposed by Duncan Watts and Steven Strogatz (1998), by randomly replacing some links of a regular network with random links, which will be explained more in Section 7.3.1.

[32] Differences of results in multiple simulation runs were only marginal, so results of one run are presented here to get an impression of possible aggregate changes. The sensitivity analysis in Section 7.3 will show the average results over ten simulation runs with different values of control parameters.

all have maximum values of 5. Not-saving group has larger variances than the saving group (see Table 32). After all the items are transformed to positive statements, it was found that evaluations from the saving group are all more positive than the average sample (see Table 22 in Section 6.2.1) while evaluations from the not-saving group are all more negative than the average.

**Table 32. Differences between saving group and not-saving group**

| Items | Minimum | Mean | SD |
|---|---|---|---|
| V8a: As long as big companies consume so much electricity as always, I don't think I should save electricity. | 2 (1) | 4.85 (4.15) | 0.422 (1.024) |
| V8b: Whether I consumer some less or more electricity, it makes no different impact on the environment. | 3 (1) | 4.76 (3.40) | 0.483 (1.290) |
| V8c: Most of the people who are important to me (e.g., friends/family, neighbors) think that I should save electricity. | 1 (1) | 2.01 (2.47) | 0.923 (0.980) |
| V8e: If I have more information about my electricity use, I am likely to consume less. | 1 (1) | 3.76 (2.62) | 1.115 (1.256) |

Note: Responses from Not-saving group are shown in brackets.
The scale ranges from 1= "is absolutely true" to 5= "is not true at all".

As consumers were roughly segmented into saving group, not-saving group and non-evaluation group, demographic profiles of the three segments are shown in Table 33. The saving group contains less female consumers, more older people (over 60 years old), more home owners, more people with income between 2601 and 5000 Euro than the total sample. In the opposite, the not-saving group contains more female consumers, less older people (over 60 years old), less home owners, less people with income between 2601 and 5000 Euro than the total sample. However, segments do not differ on gender (chi-square = 1.730; $p = 0.421$) and income (chi-square = 7.285; $p = 0.295$). Segments do differ on age (chi-square = 20.537; $p < .001$) and home ownership (chi-square = 9.609; $p < .01$) though.

**Table 33. Consumer segments for electricity saving**

| Segment | Saving | Not-saving | Non-evaluation | Total sample |
|---|---|---|---|---|
| **Female** | 33.3% | 38.9% | 32.9% | 35.3% |
| **>60 years** | 17.1% | 6.8% | 12.7% | 11.8% |
| **Income (2601-5000 Euro)** | 44.7% | 38.9% | 40.1% | 41.0% |
| **Home owner** | 55.80% | 44.90% | 38.70% | 46.2% |

Note: N varied between 492 and 517.

The following table shows efficiency distribution within groups of saving, not-saving and non-evaluation. Medium efficiency levels of households account for a large portion. Household agents own relatively high efficient electric appliances.

**Table 34. Efficiency distribution within different groups for saving electricity or not**

| | | | efficiency group | | | Total |
|---|---|---|---|---|---|---|
| | | | low | medium | high | |
| saving or not | saving | N | 11 | 76 | 69 | 156 |
| | | % within saving or not | 7.1% | 48.7% | 44.2% | 100.0% |
| | not-saving | N | 18 | 100 | 80 | 198 |
| | | % within saving or not | 9.1% | 50.5% | 40.4% | 100.0% |
| | non-evaluation | N | 21 | 91 | 51 | 163 |
| | | % within saving or not | 12.9% | 55.8% | 31.3% | 100.0% |
| Total | | N | 50 | 267 | 200 | 517 |
| | | % within saving or not | 9.7% | 51.6% | 38.7% | 100.0% |

**Table 35. Group distribution for electricity saving before and after simulation**

| Group | Initial status (N) | Final status (N) |
|---|---|---|
| **saving** | 156 | 270 |
| **not-saving** | 198 | 172 |
| **non-evaluation** | 163 | 75 |

Table 35 and Figure 20 show that after normative effect diffuses through networks, the number of saving group members increased by 22%, the increase of which mainly come from the change of non-evaluation group.

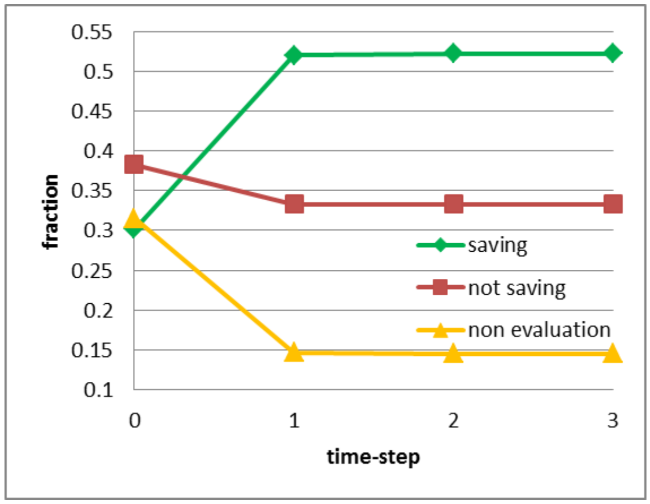



**Figure 20. Group distribution for electricity saving**

To examine the max. saving potential from households, it is assumed that an agent who belongs to the saving group will search the minimum electricity consumption from contacts/neighboring agents. The part of consumption which exceeds the minimum quantity will be counted as the saving potential of the agent. Figure 21 presents the total consumption (Unit: kWh) conditions of households in the saving group, as new members join in the group. Saving fraction is computed as the sum of saving potential divided by the total consumption at that time point. Saving fraction increased by 2%, as new members join in the group. Within the saving group, the saving fraction has minor changes after counting new members. But the saving percentage around 48% of the consumption quantity is quite high even for the saving group. In the simulated community as a whole, if assuming the community has constant consumption quantities, the initial adopters contribute a 10% saving of the total consumption quantities. With new adopters added until the simulation ends, electricity savings could account for around 20% of the total consumption, which is a rough estimation of the maximum potential only because of peer comparison, whose quantity might vary due to different energy efficiency levels (see Table 34). Also, household size and ownerships of domestic appliances were not considered in this estimation.

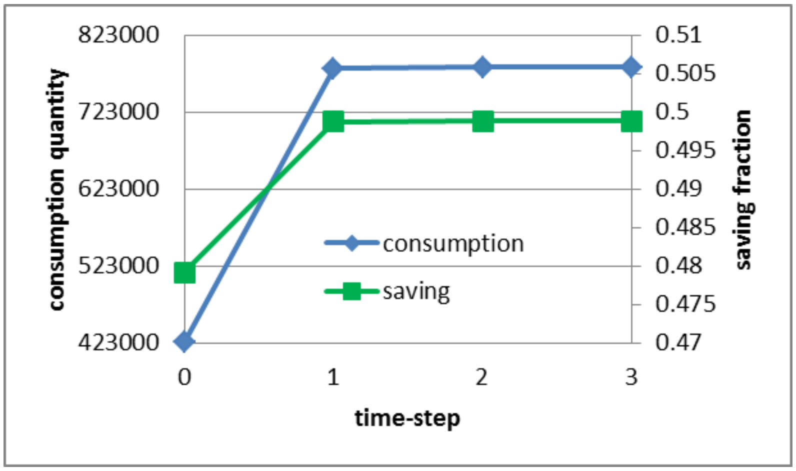



**Figure 21. Electricity consumption and savings within the saving group**

### 7.2.2 Intention to participate in smart grid applications

The respondents with a utility value of not smaller than 4, belong to the **support** group. The respondents with a utility value of smaller than 4, belong to the **not-support** group. For the rest respondents, they have some doubts about certain question items for decision factors, which result in no utility values, and they were treated as members of the **non-evaluation** group.

82 cases belong to the support group, while 92 cases belong to the not-support group. Due to a relative low level of knowledge about smart grid, a large number of people (343 cases) have not decided their standpoint yet. Not-support group has larger variances than the support group (see Table 36). After all items of measuring attitude, perceived norm and perceived behavioral control are transformed to positive statements, it was found that evaluations from the support group are all more positive than the average sample (see Table 25 in Section 6.2.2) while evaluations from the not-support group are all more negative than the average.

**Table 36. Differences between support group and not-support group**

| Items | Minimum | Maximum | Mean | SD |
|---|---|---|---|---|
| V12b: Smart grid will not be realized in Germany. | 1 (1) | 5 (5) | 4.16 (3.05) | 0.923 (0.930) |
| V12e: I support smart grid implementation because it contributes to the sustainable society. | 1 (1) | 3 (5) | 1.38 (2.77) | 0.536 (1.196) |
| V12f: I am against smart grid implementation because the costs are too high. | 1 (1) | 5 (5) | 4.61 (3.65) | 0.662 (1.032) |
| V12d: Most of the people who are important to me (e.g., friends/family, neighbors) think that it is good that I support smart grid. | 1 (1) | 4 (5) | 1.88 (2.91) | 0.674 (0.968) |
| V12g: I am against smart grid implementation because I need to allow electricity suppliers to control my consumption. | 3 (1) | 5 (5) | 4.56 (3.09) | 0.590 (1.192) |

Note: Responses from Not-support group are shown in brackets.
The scale ranges from 1= “is absolutely true” to 5= “is not true at all”.

As consumers were roughly segmented into support group, not-support group and non-evaluation group, demographic profiles of the three segments are shown in Table 37. The support group contains less female consumers, more older people (over 60 years old), more home owners, a little more people with income between 2601 and 5000 Euro than the total sample. In the opposite, the non-evaluation group contains more female consumers, less older people (over 60 years old), less home owners, less people with income between 2601 and 5000 Euro than the total sample. However, the segments do not differ significantly on gender (chi-square = 4.173; $p = 0.124$). Segments do differ on age (chi-square = 20.822; $p < .001$), on home ownership (chi-square = 18.904; $p < .001$) and on income (chi-square = 13.594; $p < .05$) though. But the demographic profile of consumers’ possible involvement in smart grid do not show very convincing differences between support group and not-support group.

**Table 37. Consumer segments for involvement in smart grid applications**

| Segment | Support | Not-support | Non-evaluation | Total sample |
|---|---|---|---|---|
| **Female** | 28.8% | 29.7% | 38.4% | 35.3% |
| **>60 years** | 19.8% | 13.5% | 9.3% | 11.8% |
| **Income (2601-5000 Euro)** | 41.8% | 47.2% | 39.2% | 41.1% |
| **Home owner** | 54.9% | 63.0% | 39.7% | 46.2% |

Note: N varied between 492 and 517.

The following table shows efficiency distribution within groups of supporting, not-supporting and non-evaluation. Medium efficiency levels of households account for a large portion. Household agents own relatively high efficient electric appliances.

**Table 38. Efficiency distribution within different groups of supporting participation or not**

| | | | efficiency group | | | Total |
|---|---|---|---|---|---|---|
| | | | low | medium | high | |
| support participation or not | support | N | 2 | 41 | 39 | 82 |
| | | % within support participation or not | 2.4% | 50.0% | 47.6% | 100.0% |
| | not support | N | 9 | 51 | 32 | 92 |
| | | % within support participation or not | 9.8% | 55.4% | 34.8% | 100.0% |
| | non-evaluation | N | 39 | 175 | 129 | 343 |
| | | % within support participation or not | 11.4% | 51.0% | 37.6% | 100.0% |
| Total | | N | 50 | 267 | 200 | 517 |
| | | % within support participation or not | 9.7% | 51.6% | 38.7% | 100.0% |

**Table 39. Group distribution for participation in smart grid before and after simulation**

| Group | Initial status (N) | Final status (N) |
|---|---|---|
| **support** | 82 | 357 |
| **not-support** | 92 | 70 |
| **non-evaluation** | 343 | 90 |

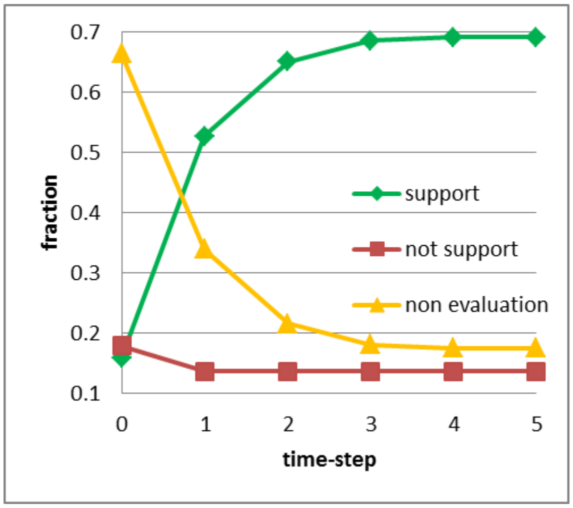



**Figure 22. Group distribution for intentions of participation in smart grid applications**

Table 39 and Figure 22 show that after normative effect diffuses through networks, the number of support group members increased by 53%, the increase of which mainly come from the change of non-evaluation group.

Question V4 asked participants whether they can imagine using smart appliances shown in Table 10. Except electric heating, the consumptions of other appliances were assumed to be the electricity shifting potential from households.

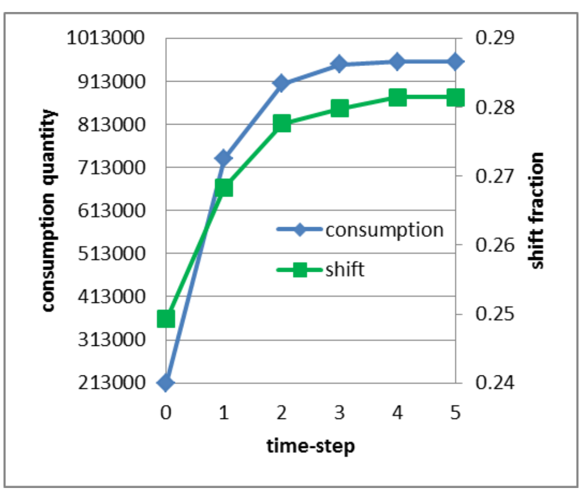



**Figure 23. Electricity consumption and shifting potential within the support group**

For each household agent, the shifting potential was estimated based on the ownership and using frequencies of appliances they accept to be controlled. The data for specific consumptions of appliances from Table 30 were used for the calculation. Figure 23 presents the total consumption (Unit: kWh) conditions of households of the support group, as new members join in the group. Shifting fraction is computed as the sum of shifting potential divided by the total consumption at that time point. Shifting fraction increased by 3%, as new members join in the group. Within the support group, the shifting fraction has minor changes after counting new members. But the shifting percentage around 25% of the consumption quantity is relatively high. In the simulated community as a whole, if assuming the community has constant consumption quantities, the initial adopters contribute a 4% of the total consumption which can be shifted. With new adopters added until the simulation ends, the load which can be shifted could be near 20% of the total consumption, which is a rough estimation of the potential only because of social pressure, whose quantity might vary due to different energy efficiency levels (see Table 38).

### 7.2.3 As "prosumer" using solar cells

The respondents with a utility value of not smaller than 4, belong to the **invest** group. The respondents with a utility value of smaller than 4, belong to the **not-invest** group. For the rest respondents, they have some doubts about certain question items for decision factors, which result in no utility values, and they were treated as members of the **non-evaluation** group.

95 cases belong to the invest group, while 238 cases belong to the not-invest group. Not-invest group has larger variances than the invest group (see Table 40). After all items of measuring attitude, perceived norm and perceived behavioral control are transformed to positive statements, it was found that evaluations from the invest group are all more positive than the average sample (see Table 28 in Section 6.2.3) while evaluations from the not-invest group are all more negative than the average.

**Table 40. Differences between invest group and not-invest group**

| Items | Minimum | Maximum | Mean | SD |
|---|---|---|---|---|
| V39a: I think it is very expensive to apply home photovoltaics for electricity generation. | 2 (1) | 5 (5) | 4.52 (3.23) | 0.727 (1.166) |
| V39b: I think it harms the environment to apply home photovoltaics for electricity generation. | 1 (1) | 5 (5) | 4.72 (4.11) | 0.767 (1.054) |
| V39d: I think applying home photovoltaics for electricity generation is modern. | 1 (1) | 5 (5) | 1.48 (2.21) | 0.861 (1.034) |
| V39h: I think it is worthwhile to invest in home photovoltaics for electricity generation. | 1 (1) | 5 (5) | 1.63 (2.23) | 0.946 (1.125) |
| V42b: Most of the people who are important to me (e.g., friends/family, neighbors) think that it is good that I install a PV system. | 1 (1) | 3 (5) | 1.53 (2.11) | 0.666 (0.912) |
| V33: I have been often informed about home installations of renewable energies. | 1 (1) | 3 (5) | 1.35 (3.80) | 0.597 (1.270) |

Note: Responses from Not-invest group are shown in brackets.

The scale ranges from 1= “is absolutely true” to 5= “is not true at all”.

As consumers were roughly segmented into invest group, not-invest group and non-evaluation group, demographic profiles of the three segments are shown in Table 41. The invest group contains less female consumers, more older people (over 60 years old), more home owners, more people with income between 2601 and 5000 Euro than the total sample. In the opposite, the not-invest group contains more female consumers, less older people (over 60 years old), less home owners, less people with income between 2601 and 5000 Euro than the total sample. And the segments do differ on age (chi-square = 43.140; $p < .001$), on home ownership (chi-square = 54.343; $p < .001$), on income (chi-square = 13.082; $p < .05$) and on gender (chi-square = 14.478; $p = .001$).

**Table 41. Consumer segments for investment in solar cells**

| Segment | Invest | Not-invest | Non-evaluation | Total sample |
|---|---|---|---|---|
| **Female** | 18.3% | 38.8% | 39.5% | 35.3% |
| **>60 years** | 20.4% | 8.5% | 11.4% | 11.8% |
| **Income (2601-5000 Euro)** | 54.4% | 35.5% | 41.7% | 41.1% |
| **Home owner** | 80.0% | 36.6% | 41.3% | 46.2% |

Note: N varied between 492 and 517.

The following table shows efficiency distribution within groups of investing, not-investing and non-evaluation. Medium efficiency levels of households account for a large portion. Household agents own relatively high efficient electric appliances.

**Table 42. Efficiency distribution within different groups of investing in PV or not**

| | | | efficiency group | | | Total |
|---|---|---|---|---|---|---|
| | | | low | medium | high | |
| invest in PV or not | invest | N | 7 | 49 | 39 | 95 |
| | | % within invest in PV or not | 7.4% | 51.6% | 41.1% | 100.0% |
| | not invest | N | 29 | 109 | 100 | 238 |
| | | % within invest in PV or not | 12.2% | 45.8% | 42.0% | 100.0% |
| | non-evaluation | N | 14 | 109 | 61 | 184 |
| | | % within invest in PV or not | 7.6% | 59.2% | 33.2% | 100.0% |
| Total | | N | 50 | 267 | 200 | 517 |
| | | % within invest in PV or not | 9.7% | 51.6% | 38.7% | 100.0% |

**Table 43. Group distribution for PV investment before and after simulation**

| Group | Initial status (N) | Final status (N) |
|---|---|---|
| **invest** | 95 | 135 |
| **not-invest** | 238 | 229 |
| **non-evaluation** | 184 | 153 |

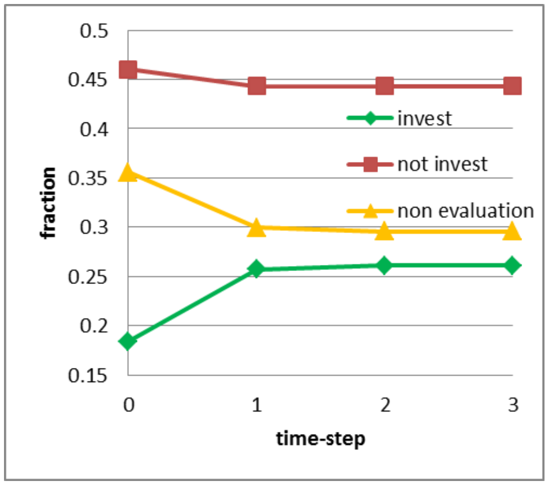



**Figure 24. Group distribution for PV investment**

Table 43 and Figure 24 show that after normative effect diffuses through networks, the number of invest group members increased by 7.7%, the increase of which mainly come from the change of non-evaluation group.

For each household agent, the possible production quantity was defined as 3900 kWh per year (installed capacity: 4.5 kWp, which needs roof space of about 30 $m^2$). Figure 25 presents the total consumption (Unit: kWh) conditions of households in the invest group, as new members join in the group. Producing fraction is computed as the sum of producing potential divided by the total consumption at that time point. Producing fraction decreased by 9%, as certain new members with large electricity consumptions join in the group. Still, the invest group can cover their own consumptions after the addition of new members. In the simulated community as a whole, if assuming the community has constant consumption quantities, the initial adopters generate electricity which takes up 25% of the total consumption. With new adopters added until the simulation ends, the quantity of produced electricity could achieve 35% of the total consumption, which is a rough estimation of the potential caused by social influence, whose quantity might vary due to different installed capacities.

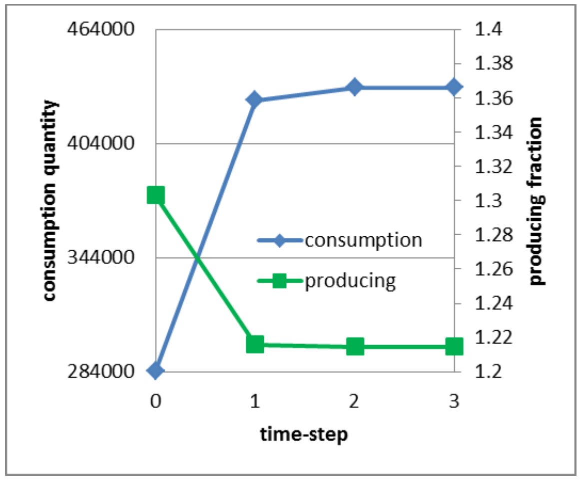



**Figure 25. Electricity consumption and producing potential within the invest group**

The conditions of adoption groups presented in Figure 21, Figure 23 and Figure 25 can be used as a reference for the development of energy autonomous community. Electricity saving and particularly electricity shifting as critical part of load management can help adapt to local produced electricity by renewable energies.

In summary, within the adoption groups, the saving or shifting or producing fraction has minor change after the joining of new members. One reason could be the denominator (electricity consumption quantity) has relatively high values compared to limited savings/load shift/production. The other reason could be contributions from initial adopters are already substantial. Nevertheless, in the simulated community/society as a whole, if assuming the “residential sector” has constant consumption quantities, with new adopters added until the simulation ends, electricity savings could account for from around 10% to 20% of the total consumption quantities, the load shift could increase from 4% to close to 20% of the total consumption, and the produced electricity could account for from 25% to 35% of the total consumption.

## 7.3 Sensitivity analysis

In the sensitivity analysis, ten repetitive simulation runs were performed for each combination of parameter setting. The expected number of adopters reported in the figures below is the average over ten runs.

The expected number of adopters (see Figure 20, Figure 22 and Figure 24) stabilized in short time steps. Hence the speed of diffusion could not be analyzed. Since the time-step has no meaning of real time intervals, it only shows possible development space while the time needed in reality could be quite long. One reason for the stabilization coming so quickly is the small number of agents: 517. For smart grid participation due to a great portion of non-evaluation agents, the normative effect seems larger than the other two behaviors.

Other assumptions:

- The simulation only considered the social influence caused by adopters, the influence diffusion of non-adopters were ignored. Once agents have adopted a certain behavior, it is assumed that they will not alter their stances as adopter group members.
- Agents have their own predetermined susceptibility to social influence ($Social_i$, perceived norm question items). The simulations did not consider their changes over time.

### 7.3.1 The effect of network structure

Communication network structure is recognized to have an important role in the diffusion process (Rogers, 1983; Kiesling et al, 2012). In this part, the influence of network structure (three main structures—regular, small world and random graph models) with varying average path lengths and clustering coefficients on simulation results will be tested. All networks are treated as unweighted, i.e. tie strengths will not be considered.

A regular network is a network where agents make edges with the **k**[33] nearest neighbors. Each agent has the same number (k) of links.

A random network (Erdos and Renyi, 1959) consists of completely random chosen peers (pairs of nodes). Each individual edge is connected randomly.

Small world networks (Watts and Strogatz, 1998) emerge as the result of randomly replacing some links of the regular network with random links. Each individual edge within the regular network may be rewired with probability p (**rewiring-probability**), which is, removing an existing edge and forming a new edge at random. Short-cut links generated by this process shorten the average path length between the agents, leading to the small world phenomenon, owning both a short average path length and a high clustering coefficient.

Density as one basic network characteristic, average degree k will be used for its measurement. A density of 100% means each person/node in the network knows everyone else. In general, highly dense networks are more vulnerable to penetrations while groups with lower densities are more resistant (Strang, 2014). Deffuant et al (2005) suggested extremists with very definite opinions can strongly affect adoption when the density of the social network is high. Alkemade and Castaldi (2005) found that if the network is sufficiently dense, the propagation may be limited. If nodes have a large number of neighbors, the perturbation may be difficult to diffuse. As the network density increases, diffusion cascades[34] occur more unlikely.

Average path length (APL)—the average distance between any two nodes in the network—is a measurement of connectivity of the network. APL is described as the sum

[33] k is the average number of connections each node has in the network, which represents the network density. The density of a network is found to be independent of the number of nodes in the whole network (Kunegis, 2011).

[34] A cascade occurs when a person observes actions of others and engages in the same act as the information outweighs his or her own judgment (Easley, 2010).

of shortest distance[35] between all pairs of nodes, divided by the total number of pairs/edges (Newman, 2001).

Clustering coefficient (CC) gives a representation of how clustered the network is and measures the probability that the friends of my friends are my friends. The CC of a node can be calculated as the ratio between the number of existing edges among the neighbors of the node and the maximum possible edges among neighbors. The CC for the entire network is averaging the clustering coefficients of all the nodes (Watts and Strogatz, 1998).

The average path length (APL) and the clustering coefficient (CC) are high for regular networks. The APL and CC are low in a random network. Networks with short average path lengths and high clustering coefficients are considered as small world networks. Small world networks show a higher level of clustering than random networks (Alkemade and Castaldi, 2005).

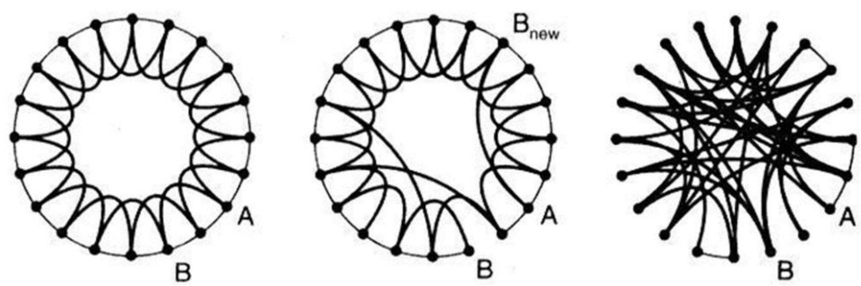



**Figure 26. Regular network, small world network and random network (k = 4)**

**Source:** Lada Adamic, 2014.
Lecture slides of Social Network Analysis, week 5: Small world network models, optimization, strategic network formation and search. School of Information, University of Michigan.

Kiesling et al (2012) reviewed interaction topologies between agents used in social influence models. Small world networks are found to be the most popular structure employed in diffusion research (Janssen and Jager, 2002; Alkemade and Castaldi, 2005;

[35] The distance denotes the number of links that have to be followed to get from one agent in the network to the other.

Deffuant et al, 2005; Delre et al, 2007b; Kocsis and Kun, 2008; Thiriot and Kant, 2008; Choi et al, 2010). Studies comparing diffusion in regular, small-world and random networks indicate that innovations diffuse faster in more regular networks than in more random networks (Delre et al, 2007b; Choi et al, 2010). One reason could be that individuals are exposed to more social influence in clustered networks and hence decide to adopt sooner (Delre et al, 2007b). Choi et al (2010) explain that randomness in the network typology makes it more difficult for a new product or innovation to build up network benefits at the initial stage. However, higher clustering could slow diffusion, as it increases the overlap of contacts among neighbors (Rahmandad and Sterman, 2008), or non-adopters dominate separate clusters while the pressure from adopters in the network could be scattered and weak (Delre, 2007). In this way, random networks may exhibit more peak adoption and lower peak times than regular and small-world networks (Rahmandad and Sterman, 2008; Bohlmann et al, 2010). Kuandykov and Sokolov (2010) suggest that the diffusion speed depends on information equality. Innovation diffuses much faster in a network with higher information equality than the lower information equality network, which indicates that random networks with higher information equality could have shorter diffusion time. However, in networks with hubs (like small-world networks) initial adopters are more visible for other neighboring nodes than in random networks, which facilitates the diffusion (Kuandykov and Sokolov, 2010). Similarly, Delre et al (2010) found that innovations are more likely to spread and be adopted by more consumers when consumer agents are connected in small-world networks than regular and random networks. But Kim et al (2011) found that network structure little affected the diffusion results although the speed of diffusion is determined by network parameters.

In general, social influence on the non-adopter neighbors in the clustered group is stronger than the not-clustered (Delre et al, 2007b). The influence of the three network structure on the final status (expected number of adopters) of simulations in this study will be tested below. Small-world networks with rewiring probabilities p {0.001, 0.005, 0.01, 0.05, 0.1}[36] which characterizes the degree of randomness in the network were tested. When the rewiring probabilities are close to zero, the network tends to be completely clustered (regular network, p = 0). When the rewiring probabilities are close to one, the network tends to be random and agents are not clustered (random network, p = 1).

Simulations in Section 7.2 used the common network parameters: rewiring-probability = 0.1, k = 4. As the rewiring-probability increases, the APL and clustering coefficient of the network will decrease. However, Figure 27, Figure 28 and Figure 29 show that expected number of adopters have few differences in different networks if k keeps the same. Only when k = 8 the increasing randomness of network exhibits much more adopters of saving electricity (see Figure 27) at the peak, which has been mentioned by Rahmandad and Sterman (2008) and Bohlmann et al (2010). For conditions of investment in PV (see Figure 29) though, when k >= 6, the increasing randomness of network exhibits less adopters at the peak, which is consistent with Choi et al (2010). Nevertheless, one reason of the few differences among networks might be the small number of agents in the system. As is described above, regular, small-world and random networks usually induce different diffusion speed. The simulations here concentrate on estimating the level of behavior changes brought by social norms, whereas how long it will cost is not a focus. Hence differences caused by different network efficiencies cannot be obviously observed in this study.

The influence of k value is also tested, as it represents the network density. The results in the following figures indicate that there is an optimal initial average degree (k, the number of neighbors each agent has)—k = 6 for electricity saving and PV investment, k = 20 for smart grid participation—when trying to achieve max. number of final adopters, because it will influence the fraction of neighbors who have already adopted a certain behavior. As k value increases above a threshold, it might become more unlikely that the fraction of adopter neighbors takes an advantage. For participation in smart grid

[36] Because the cluster coefficient and the average path length undergo large variations in the range (0.001 < p < 0.1).

applications, the expected number of adopters seems to go up with increased k value. One reason might be that there are a large portion of non-evaluation members in the sample. As k value increases, it is more likely to have supporter neighbors and hence the fraction of adopter neighbors could take an advantage. This finding is consistent with what Alkemade and Castaldi (2005) suggested: if the network is sufficiently dense, the propagation may be limited. Even though the network density still increases, the spread is more unlikely to continue.

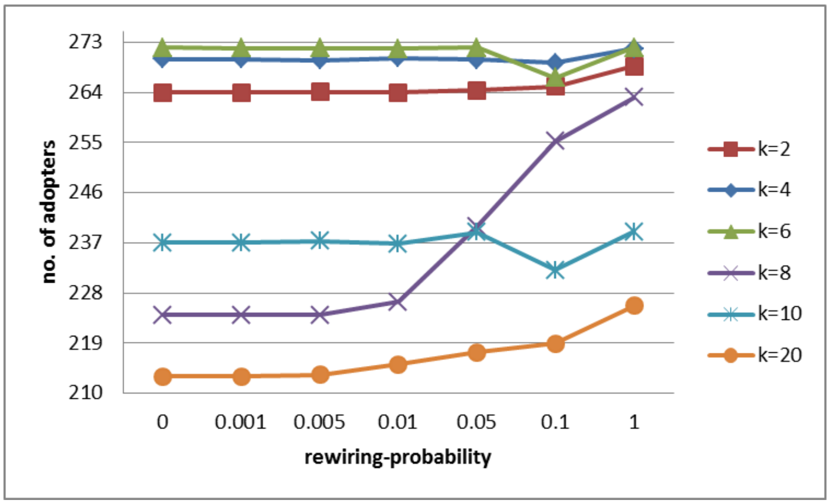



**Figure 27. Expected number of adopters of saving electricity with different parameter settings**

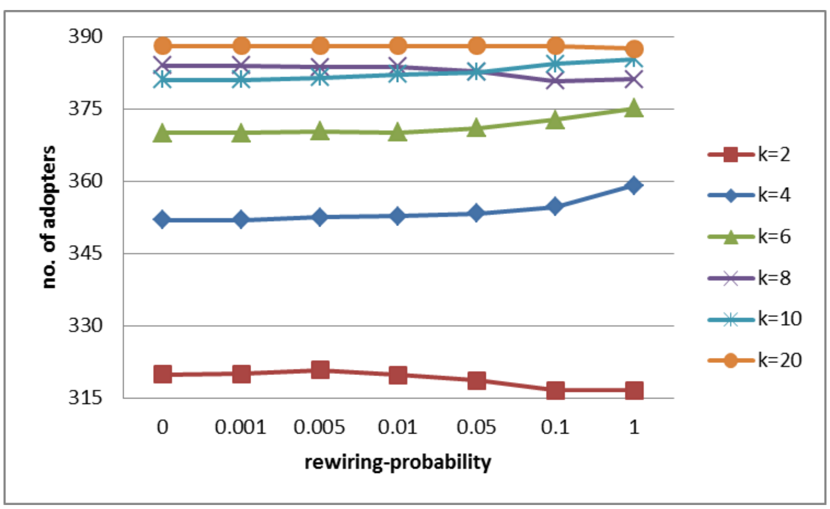



**Figure 28. Expected number of adopters participating in smart grid with different parameter settings**

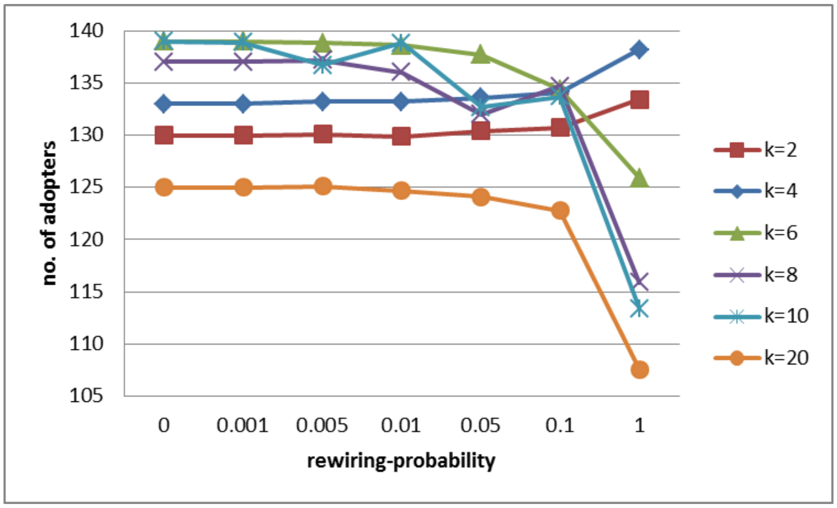



**Figure 29. Expected number of adopters investing in PV with different parameter settings**

### 7.3.2 The effect of influenced rate

If agent i belongs to the non-evaluation group, agent i counts the number of adopters and non-adopters within network contacts. If agent i values the social influence (check the $Social_i$ value) and the adopter group takes an advantage, then agent i would join the adopter group with a probability—named "influenced rate".

Section 7.2 show the conditions of number of adopters when influenced rate = 1 (network parameters: rewiring-probability = 0.1, k = 4). If influenced rate is zero, the fact that neighboring adopters prevail over non-adopters cannot directly decide whether or not agent i would join the adopter group. Only after updating social utility value (fraction of i's neighbors who have already adopted a certain behavior), when $Utility_i$ of agent i is larger than 4 agent i will be assumed to join the adopter group. In general, the higher the influenced rate is, agent i would be more likely to make an adoption decision. The effects on the final status (expected no. of adopters) due to different influenced rate were tested, the result of which is shown in the following figures. They give the mean value of no. of adopters and the percentage of adopters over ten simulation runs.

The increase tendency is consistent with earlier guess. Percentage difference due to the change of influenced rate for saving electricity is about 3%, for smart grid participation is about 43% and for PV investment is about 5%. The higher the number of non-evaluation agents is, the effects caused by influenced rate are found to be larger. In addition, the effects are nearing saturation when influenced rate is 0.6 for saving electricity, 0.5 for smart grid participation and 0.3 for PV investment.

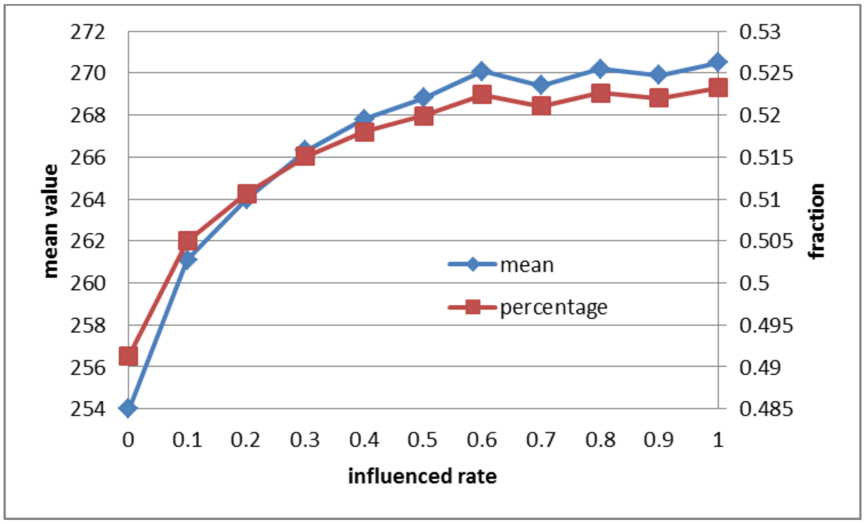



**Figure 30. The effects of influenced rate on the final status for saving electricity**

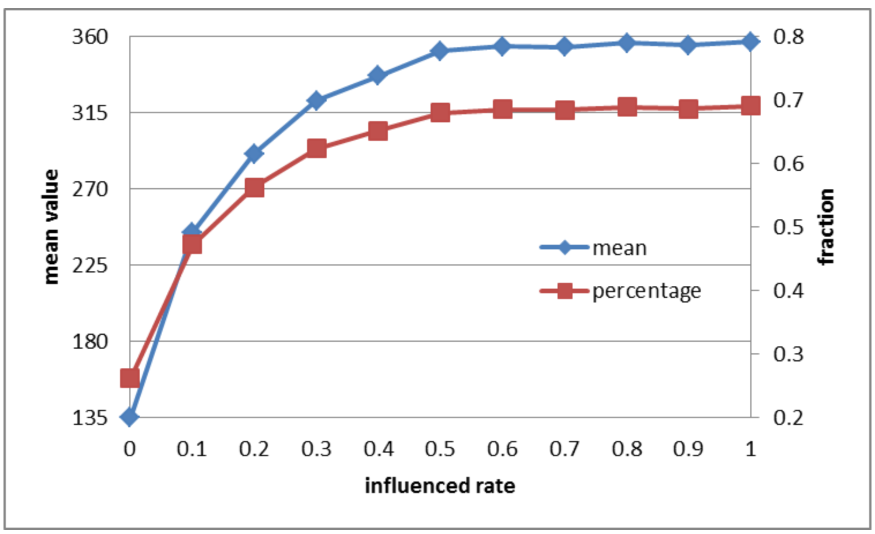



**Figure 31. The effects of influenced rate on the final status for participation in smart grid**

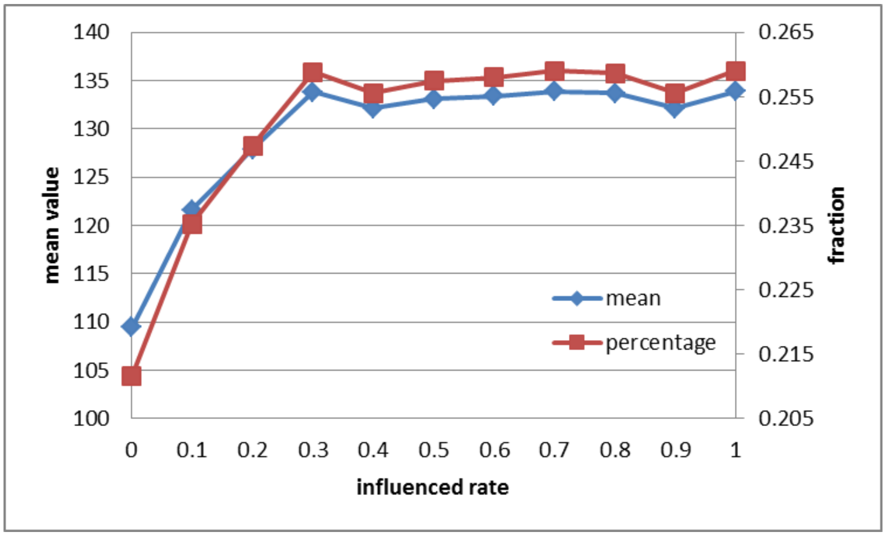



**Figure 32. The effects of influenced rate on the final status for PV investment**

## 7.4 Scenarios

Two scenarios will be carried out to explore the combined effects of cost factor and the diffusion of social norms as non-economic motivations. As citizens are more price-insensitive in electricity saving compared to PV and smart grid participations, the analysis here focuses on smart grid participations and PV investment. In the scenarios, the network parameters are: rewiring-probability = 0.1, k = 4. As shown in Figure 33, the initial status is obtained from the empirical survey. Sections 7.2.1, 7.2.2 and 7.2.3 have examined the normative effect when social norms diffuse in the social network (**scenario 0**). In scenarios of 1 and 2, the simulations firstly consider the influence of adjusted costs on consumers' decision, and then see where it goes together with normative effect. The final status of scenarios is treated as the total effects of cost effect and social network effect.

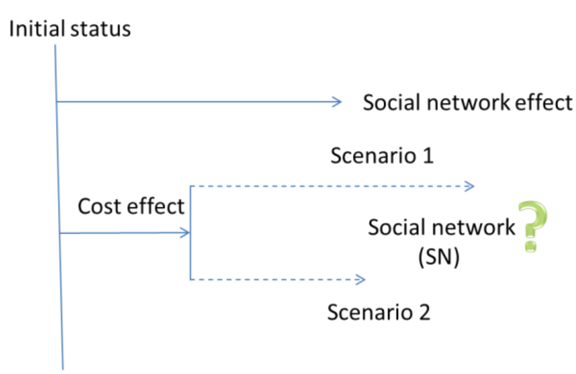



**Figure 33. Scenario description**

In Scenario 1, relevant costs will greatly decrease (maybe due to subsidies). The question item which represents agents' opinions about cost is assumed to change, with 1 unit of increase. After the cost barrier is relieved, consumers are supposed to support the corresponding technology more. But maximum value is 5, therefore consumers who have chosen 5 earlier keep the same.

In Scenario 2, relevant costs will greatly increase (maybe subsidy amount goes down or even subsidies are ended). The question item which represents agents' opinions about cost is assumed to change, with 1 unit of decrease. After the cost barrier is more severe, consumers are supposed to support the corresponding technology less. But minimum value is 1, therefore consumers who have chosen 1 earlier keep the same.

**Table 44. Explanation of the opinion change assumptions in scenarios**

| **Agent i** | **Code** | **Question** | **1=is absolutely true** | **2=is quite true** | **3=is partially true** | **4=is hardly true** | **5=is not true at all** |
|---|---|---|---|---|---|---|---|
| **Initial status** | V12f | I am against smart grid implementation because the costs are too high. | | a | | | |
| **Scenario 1** | V12f | | | → +1 | a+1 | | |
| **Scenario 2** | V12f | | a-1 | ← -1 | | | |
| **Initial status** | V39a | I think applying home photovoltaics are too expensive. | | | | b | |
| **Scenario 1** | V39a | | | | | → +1 | b+1 |
| **Scenario 2** | V39a | | | | b-1 | ← -1 | |

After utility values are recalculated, the number of members in each group and the share of changed number in the sample (517 cases) are shown in Table 45 and Table 46. Table 45 and Table 46 show that social network effect in scenario 1 is stronger than that in scenario 0 (SN effect only), which indicates that economic incentives reinforced the normative instrument. Social network effect in scenario 2 is weaker than that in scenario 0, which indicates that economic incentives weakened the normative instrument. Especially for PV investment, when the costs of applying home photovoltaics are too high, the cost impact is so strong and dominated, normative motivations cannot turn around this undesirable situation. Besides, it can be seen that cost factors bring higher adverse effects than positive effects by comparing the two scenarios.

**Table 45. Result comparison for participations in smart grid applications**

| | support | not-support | non-evaluation | % of change |
|---|---|---|---|---|
| Initial status | 82 | 92 | 343 | |
| SN effect only | +275 | -22 | -253 | 53% |
| Cost effect 1 only | +4 | -4 | | 0.8% |
| Scenario 1 | +286 | -25 | -261 | 55% |
| Cost effect 2 only | -20 | 20 | | -4% |
| Scenario 2 | +245 | -15 | -230 | 47% |

**Table 46. Result comparison for PV investment**

| | invest | not-invest | non-evaluation | % of change |
|---|---|---|---|---|
| Initial status | 95 | 238 | 184 | |
| SN effect only | +40 | -9 | -31 | 8% |
| Cost effect 1 only | +24 | -24 | | 4.6% |
| Scenario 1 | +78 | -34 | -44 | 15% |
| Cost effect 2 only | -23 | 23 | | -4.4% |
| Scenario 2 | -1 | 20 | -19 | -0.2% |

# 8. Discussion

## 8.1 Roles of households in the smart grid implementation

Chapter 2 has mentioned that besides as passive electricity users and bill payers in the traditional grid, households can be more informed and engaged in the smart grid, such as adjust consumption during heavy-load times and generate own electricity. End consumers are expected, together with suppliers, to make the whole electricity system operate in a more efficient way. The implementation process also involves consumers' adoption of relevant products like smart appliances and solar panels. Whether consumers are aware of these opportunities and actively take adaptations matters to the success of the future system. Understanding the influential factors behind is also indispensable.

As explained in Section 5.3.1, electricity consumption is largely dependent on the household size, ownerships of appliances and energy efficiencies of appliances, households tend to be more willing to use efficient appliances to save energy. This is consistent with findings of Poortinga et al (2003): technical improvements were more receptive than behavioral measures in household energy-saving. In my survey, 51.6% of respondents own appliances at medium efficiency levels and 38.7% have high energy efficiency. But further curtailment would be difficult, as only 33% of respondents in the survey think it is easy to reduce consumption by 10%. 54.7% of respondents received information about saving electricity frequently. Most respondents would like to receive information 3-4 times each year, maximum one time every month. In terms of electricity saving behavior, individual attitude towards saving own electricity has the biggest effect (see Section 6.2.1). It largely promotes saving behaviors if individuals believe that their efforts can actually make a difference in the environment, which is consistent with existent studies mentioned in Section 3.3 (e.g., Gilg et al., 2005; Sütterlin et al, 2011). Without information barrier and with support from important others like friends in saving electricity, citizens will be more likely to save electricity. These findings are consistent with those in Section 3.2.1, nonetheless, more barriers (such as inconvenience) especially in habit changes could be explored in the future research.

Recently Energiewende has been heatedly discussed in Germany, and smart grid is earning some attention as well. Section 5.3.2 has mentioned that the more citizens know about Energiewende, the more likely they are to know something about smart grid. Approximately 80% of respondents feel that they know Energiewende quite well including its advantages and disadvantages. About 40% of respondents have heard something about smart grid, which indicates they have relative high levels of awareness because the sample has higher education and higher interest in energy topics, and some invited respondents even engage in energy research. With regard to smart meter and smart appliances--key elements of smart grid, only 8.2% of the respondents have installed smart meters at home; dishwashers and washing machines are the most accepted appliances that can be automatically controlled. Interestingly, when participants were asked about their preferred options dealing with the energy demand under no wind and no sunshine circumstances, the most acceptable option would be “small decentral energy storage”, followed by “large central energy storage” and “reduction of electricity consumption through contracts”. In addition, before negotiating electricity tariffs most respondents insist that basic needs (e.g., lighting, fridge and freezer) should be satisfied. The least preferred option is cutting off electricity even though a rebate would be given. In terms of willingness to participate in smart grid applications, individual attitude towards smart grid has the biggest effect (see Section 6.2.2), which is consistent with findings in Toft (2014) and Kranz et al (2010). It largely promotes participation if individuals believe that smart grid can contribute to the sustainable society and the costs are not high. Without threat of feeling controlled in electricity consumption, citizens tend to more willingly participate in smart grid applications. Unexpectedly, the control factor and perceived norm have influence on individual attitude towards smart grid. Support from important others in smart grid will impact attitude directly and then indirectly increase citizens’ willingness to participate. Venkatesh and Davis (2000) mentioned this as an internalization effect that consumers interpret information from important others as evidence and their intentions will then be influenced by attitudes.

For renewable energy technologies, most people support their development generally (For more details, please see Section 5.3.3). But when it comes to home renewable energy installations, 39.1% of respondents were never informed about it. The living status of respondents as renters cannot be ruled out as one reason behind. Still, most people have some indirect experience of wind or solar energy facilities. 8.2% of respondents have first-hand experience of wind energy facilities, while 29.5% have first-hand experience of solar cells. Citizens have great faith that in future photovoltaics will be everywhere in Germany. Among the people who have invested in solar cells, 81.2% of them would recommend acquaintances to install a rooftop PV system. Regarding installing a rooftop solar system at home, benefiting the environment was perceived to be the most important advantage. The least important advantage is independence from electricity supplier. Cost factor is a potential barrier, especially when a number of people are not clear about the maintenance costs. In terms of PV investment behavior, behavioral intention mediates relations between attitudes and behavior. Perceived behavioral control has the biggest effect on PV investment behavior (see Section 6.2.3). Without information and cost barriers, more probably they will make the investment decision. In the survey there is only one imaginary question item measuring the construct "Intention to install PV on the roof", which excludes certain constraints in reality (e.g., living status as an owner or renter, economic aspects). The more positive attitudes citizens hold toward photovoltaics, more probably that they tend to invest. But perceived norm and perceived behavioral control do not appear as predictors of the intention. Rather, support from important others in PV installations will impact attitude directly and then indirectly increase citizens' intentions. The question item to measure behavioral intention needs to be better designed, and further examination of perceived norm is demanded in the future research.

## 8.2 Implications from TPB applications

This study applied the theory of planned behavior (TPB) in the new context of smart grid, in order to examine to what extent TPB models can explain the important roles of private consumers—saving electricity, involvement in smart grid applications and solar panel investment. The explanatory power of TPB constructs—attitude, perceived norm, and perceived behavioral control—varies across behaviors. The proposed model (Figure 8) accounted for 32% of the variance in the electricity saving behavior, smart grid acceptance model (Figure 12) explained 56% of the variance in the intention to participate in smart grid applications, and the model shown in Figure 17 accounted for 45% of the variance in solar panel investment. Therefore these investigations in the smart grid environment broaden the range of TPB applications and also one German sample was provided.

The relative importance of TPB constructs—attitude, perceived norm, and perceived behavioral control—varies across behaviors. The findings in the study reconfirm that attitude is the most influential factor of individual electricity saving behavior, as well as of citizens' intentions to participate in smart grid applications. Perceived behavioral control and perceived norm are the following important predictors of electricity saving behavior. Perceived behavioral control also follows attitude as the second influential factor of individual intention to participate in smart grid applications. Unexpectedly, it was found that perceived control and perceived norm have influence on individual attitude towards smart grid. Support from important others in smart grid will directly impact attitude and then via attitude indirectly increase citizens' willingness to participate in smart grid applications. These need further investigations in the future research.

In the context of PV investment it reconfirms that behavioral intention mediates relations between attitudes and behavior. Besides, perceived behavioral control is found to have the highest impact on PV investment behavior. Attitude toward home PV is the only one determinant of intentions to install home photovoltaics. Perceived norm and perceived behavioral control were not proved to be direct predictors of the intentions. Perceived norm was found to directly impact attitude and then via attitude indirectly influence intentions. It is not easy to contain renters as potential investors in solar panels. Better measurement tools for behavioral intentions are demanded to reexamine the determinants.

With respect to perceived norms, this research shows their possible way of influencing behavioral intentions via the internalization effect mentioned by Venkatesh and Davis (2000). Instead of directly influencing one's intention, the person might interpret information from important others as evidence about reality, through which he or she forms attitude toward new technologies and then attitude determines the behavioral intention. These findings are consistent with the indirect effect of social norms on the intention found by studies in pro-environmental behaviors (Armitage and Conner, 2001; Bamberg and Möser, 2007).

## 8.3 Implications for marketing strategies

### 8.3.1 Consumer segments

Consumer segmentation provides a tool for the design of tailored marketing or policy strategies in the adoption of products or behaviors. It has been successfully used to speed the diffusion of various products, as well as campaigns to promote social behaviors, but only recently applied to the electric utility sector (Moss and Cubed, 2008). By motivating target interest group to action through targeted and relevant messages, effective use of this approach may lead to faster and more widespread adoption of new technologies, which could help achieve ambitious goals of Energiewende.

Segmentation of residential customers typically uses demographic characteristics (e.g., age, gender, income) or focuses on attitudinal and behavioral variables (Moss and Cubed, 2008; Sütterlin et al, 2011). From Section 7.2.1 it can be noted that identified initial adopters who are likely to save electricity (i.e., the saving group) tend to be home owners and older people. They believe individual efforts can actually make a difference in the environment, they do not lack relevant information, and they perceive higher social pressure in saving electricity. From Section 7.2.2 it can be noted that identified initial adopters who are likely to support smart grid implementation (i.e., the support group) tend to be home owners, higher in income, and older people. They believe that smart grid can contribute to the sustainable society and the costs are not quite high, they have less fear of feeling controlled in electricity consumption, and they perceive higher social pressure in supporting smart grid. From Section 7.2.3 it can be noted that identified initial adopters who are likely to invest in solar panels (i.e., the invest group) tend to be male, home owners, higher in income, and older people, without information and cost barriers. They hold quite positive attitudes towards investment especially because it benefits the environment, and they perceive higher social pressure in PV investment.

Demographic criteria was found to be less appropriate in profiling energy consumers than attitudinal and behavioral criteria (Diamantopoulos et al., 2003; Rowlands et al., 2003; Diaz-Rainey and Ashton, 2010; Sütterlin et al, 2011). Hence the psychological variables (attitudes, perceived norm and perceived behavioral control) were used to segment consumers[37] and identify initial adopters to spread influence in the simulation. In the early stage of an innovation, early adopters are crucial for further diffusion particularly when they tend to be opinion leaders willing to share knowledge and experience with others.

For electricity saving behavior, as described in Figure 8 (see Section 6.2.1), attitude towards saving electricity has the biggest effect on saving behavior. The more positive attitude citizens hold towards saving electricity, it is more likely that they save electricity. And if the campaign conveys the message that individuals do believe that their efforts can actually make a difference in the environment, it will raise awareness of their energy use (esp. users with large consumptions) and promote more conservation actions (Sütterlin et al, 2011).

For PV investment behavior, as described in Figure 17 (see Section 6.2.3), the information and cost factors matter more to individual investment decision. Barriers to adoption (e.g., financing, staffing capacity) need to be addressed in the campaign.

[37] Based on the weighted utility of individual attitudes, perceived norm and perceived behavioral control, consumers were roughly segmented into adopter group, non-adopter group and non-evaluation group.

Rooftop photovoltaics can target home owners, while community renewable energy initiatives could be open to local citizens in general.

For smart grid participation, as smart grid is new and unknown, the early adopters tend to be those with positive attitudes towards new technologies, specifically smart grid, and would like to bear certain risks or have a relative low level of resistance to the situation that home appliances can be remotely controlled occasionally. The campaign should clearly address the control issue and investment costs. For example, citizens could freely switch operation modes of appliances between fully automatic control, setup procedure ("set and forget") and manual control, which allows citizens to choose different levels they prefer to be involved (Timpe, 2009).

### 8.3.2 General marketing strategy

For consumers who belong to the adoption group regarding electricity saving behavior or smart grid participation or PV investment, they all show positive attitudes towards benefiting the environment above average (V8b, V12e, V39b), while the non-adoption group below average. Therefore, the campaign messaging around green advocates can motivate people who state environmental considerations as an important factor in decisions to participate in smart grid applications. An explanation is needed between the application and its environmental impact. Then potential adopters could be aware that such technology exists and make the connection.

### 8.3.3 Promoting smart grid participation

Correlations were found between electricity saving behavior and willingness to participate in smart grid applications (Pearson's $r = 0.368$, $p < .001$), also between PV investment and willingness to participate in smart grid applications (Pearson's $r = 0.378$, $p < .001$). 32.6% of respondents who have invested in solar cells are willing to participate in smart grid applications, while 29.5% of respondents who save electricity would like to participate in smart grid applications. Therefore, another easy way to find potential adopters of smart grid applications could start from those people who already installed green technologies, like photovoltaics and heat pump. On one hand, they have direct experience of new technologies, which reduces perceived uncertainty and complexity of the innovation. The purchase and installation costs could be a smaller problem to them (Toft and Thøgersen, 2015). On the other hand, they have electricity flexibilities which could be well combined with smart grid applications. Together, using the two systems would enable home electricity operated in a more efficient and optimal way and they reinforce people's understandings (e.g., benefits such as saving electricity and money) of both systems.

### 8.3.4 Social norms approach

Social norms approach is a marketing technique that attempts to change behaviors by delivering normative information. This tool has emerged as an alternative to more traditional approaches such as information campaigns and has been proved successful in influencing various behaviors including pro-environmental behavior (Schultz et al, 2007; Harries et al, 2013). Social norms approach interventions or social norms marketing campaigns typically use descriptive norms—what relevant others do in a given situation, and injunctive norms—what relevant others think people should do (Rettie et al, 2013). Trying to prevent boomerang effects, adding injunctive message to descriptive normative information may make it possible that people above the norm do not feel that they deviate from others and do not decrease targeted behaviors. And the same message could serve to increase desirable behaviors of individuals below the norm (Schultz et al, 2007). As electricity consumption emerged as a key topic in policies, social norms approach began to solve the new problem such as reducing domestic electricity consumption (Harries et al, 2013).

For electricity saving behavior, as described in Section 4.2, normative messages could achieve household energy savings of 10% (Nolan et al, 2008), while two studies identified reductions of around 2% (Ayres et al, 2009; Allcott, 2011). However, it is not easy to distinguish the impact of social comparison from other used intervention techniques like individual feedback (e.g., historical consumption) (Harries et al, 2013). To figure out the additional behavioral changes brought by social norms, the agent-based simulation was used in this thesis. To examine the maximum saving potential, in the simulation households can be aware of those contacts with lower consumptions, while intervention studies normally use average consumptions for comparison. It was found that max. 20% of total consumptions in the simulated community could be saved due to the persuasive power of social comparison and communication.

For PV investment behavior, as described in Section 4.3, peer effects were identified as one important factor of boosting PV installations. But the effect diminishes over time and distance. As some citizens do not own the houses but live as renters, the PV diffusion in the simulations do not set the ownership limit and renters could still choose to invest in other forms. The results of this study show a possible increase of members in the invest group by 7.7% after social norms pass networks. In the simulation, it assumes that after one household agent decides to invest in solar panels, the possible production quantity of electricity is 3900 kWh per year. Differently, in reality, members in the invest group could have diverse choices for PV installed power, and they can participate in community-owned energy cooperatives as well. This study only roughly estimated their possible contributions in electricity production.

For smart grid participation, as its outcomes are unclear and more uncertain, information on others' behaviors and expectations could be used as a kind of evidence or proof being proper. The simulation results show a very optimistic increase of members in the support group by 53% after social norms pass networks. In real life people will make their decisions in a more constrained way which involves infrastructure, cost and technical characteristics of smart grid. Nevertheless, intervention studies using normative feedback indicate that social norms campaigns could be very effective if appropriate reference group is used. Therefore, in the implementation it is suggested to provide consumers with multiple choices such as own historical consumption data, neighbors (zip code, or in the same buildings), and similar houses (household size and consumption levels). People could even invite friends to join a communication network similar to "Facebook" but based on existing forums sharing tips in saving electricity or PV installations. Some applications in smart grid are not as visible as installations of solar panels, such communication networks are a source of knowledge with hardly any cost and open for 24 hours each day. It can gather people with similar problems, help sustain consumer interest in feedback and extend engagement, as well as influence bystanders to try available options.

Furthermore, as new members of adopter groups mainly come from the change of non-evaluation group, the social norms marketing campaigns should target those people who are hesitant and have no clear standpoints yet. And it demands attention that the synergy effects when several incentives are used, as the scenarios showed, adverse effects of high costs can be very dominant, although without the diffusion of disapproval opinions in the simulation, positive changes caused by the dissemination of social norms are still weak.

## 8.4 Limitations of the study

As the sample in the survey is unrepresentative of German citizens as a whole, the results including simulation based on it should be interpreted with caution. More male, people with higher education and higher income have participated in the survey. The studied sample has higher interest and more knowledge in energy topics than the general public, and thereby the degree of their favor in the environment and relative high rate of acceptance could be overestimated.

The questionnaire could be better designed with at least three items to measure each construct, and then the results will be more convincing. Especially for perceived norm evaluation, as described in Section 6.2, some have direct influence on the behavior, and some have indirect effects via attitude on the adoption intention. Although social norms could actually exert influences either through the internalization of information from other citizens (indirect) or through compliance with others' expectations (direct), the poorly designed question (especially imaginary item for intention--question V38--excluding certain constraints) did not help make definite inferences.

With larger size of agents in the simulation and different numbers of initial adopters, the observed normative effects might be different. The speed of diffusion affected by factors like network structures needs to be examined in the future research. Besides, the simulation only considered the positive social influence caused by adopters, but the influence diffusion caused by non-adopters was ignored. Under disadvantaged situations like high cost or strong resistance due to privacy or control issues, the contagion of disapproval opinions could be powerful as well.

# 9. Conclusion

Compared to technological aspects of smart grid, research on consumer preferences and acceptance is underdeveloped. This thesis has explored possible roles of individual consumers in the smart grid implementation and in detail analyzed the influential factors of their electricity saving behaviors, their intentions to participate in smart grid applications and investing in solar panels for electricity generation.

The explanatory power of TPB constructs—attitude, perceived norm, and perceived behavioral control—varies across the three target behaviors/behavioral intentions. Attitude, perceived norm, and perceived behavioral control accounted for 32% of the variance in the electricity saving behavior. Smart grid acceptance model explained 56% of the variance in the intention to participate in smart grid applications. Behavioral intention and perceived behavioral control explained 45% of the variance in investment behavior in solar panels. These investigations in the smart grid environment broaden the range of TPB applications and also one German sample was provided.

As the smart grid concept is not well understood by most people outside the relevant technology industries, education program and information campaigns are needed, in which social norm approach is worth more attention, ascribable to the considerable impact caused by the diffusion of norms through social networks.

For adoption of these three behaviors, attitude towards benefiting the environment is one key determinant. And those adopters all show positive attitudes above average (V8b, V12e, V39b), while the non-adopters are below average. Therefore, the campaign messaging around green advocates can motivate people who emphasize environmental considerations to participate in smart grid applications.

For photovoltaics investment, the information and costs matter more to individual decision than environmental concern. Correlations were found between PV investment and willingness to participate in smart grid applications (Pearson's $r = 0.378$, $p < .001$), and also between electricity saving behavior and willingness to participate in smart grid applications (Pearson's $r = 0.368$, $p < .001$). Early participants in smart grid applications are suggested to start from those who already installed green technologies, like photovoltaics and heat pump. On one hand, they have direct experience of new technologies, which reduces perceived uncertainty and complexity of the innovation. The purchase and installation costs could be a smaller problem to them. On the other hand, they have electricity flexibilities which could be well combined with smart grid applications.

The simulation tried to show the maximum space of changes caused by social influence and the results are quite promising. It was found that max. 20% of total consumptions in the simulated community could be saved due to the persuasive power of social comparison and communication. A possible increase of members in the adopter group by 7.7% can be achieved for PV investment, whereas 53% for smart grid participation, which show the great potentials in home generation and load shift. Because the influence diffusion caused by non-adopters and opponents were not considered in the simulation, the normative effect should be lower. Social norm marketing campaigns can have maximized impacts when using appropriate reference group with which a target group most associates. Therefore, in the smart grid implementation it is suggested to provide consumers with multiple choices such as own historical consumption data, neighbors (zip code, or in the same buildings), and similar houses (household size and consumption levels). People could even invite friends to join a communication network similar to "Facebook" but based on existing forums sharing tips in saving electricity or PV installations, which helps sustain consumer interest in feedback and extend engagement. The social norms marketing campaigns can first target those people who do not decide to approve or disapprove smart grid or other related technologies.

# Bibliography


Abrahamse, W., and Steg, L. (2009). How do socio-demographic and psychological factors relate to households' direct and indirect energy use and savings? Journal of Economic Psychology, 30, 711–720.

Abrahamse, W., and Steg, L. (2011). Factors related to household energy use and intention to reduce it: The role of psychological and socio-demographic variables. Human Ecology Review, 18, 30–40.

Adachi, C.W.J. (2009). The adoption of residential solar photovoltaic systems in the presence of a financial incentive: A case study of consumer experiences with the Renewable Energy Standard Offer Program in Ontario (Canada). Dissertation, University of Waterloo.

AGEB (AG Energiebilanzen e.V.) (2013). Anwendungsbilanzen für die Endenergiesektoren in Deutschland in den Jahren 2011 und 2012 mit Zeitreihen von 2008 bis 2012.

Ajzen, I. (1988). Attitudes, personality, and behavior. Chicago: Dorsey.

Ajzen, I. (1991). The Theory of Planned Behaviour. Organizational Behaviour and Human Decision Processes, 50(2): 179–211.

Ajzen, I. (2015). Theory of planned behavior: a bibliography. Retrieved July 9, 2015 from: http://people.umass.edu/aizen/tpbrefs.html.

Ajzen, I. and Fishbein, M. (1977). Attitude-behavior relations: A theoretical analysis and review of empirical research. Psychological Bulletin, 84, 888–918.

Ajzen, I., and Fishbein, M. (1980). Understanding attitudes and predicting social behavior. Englewood Cliffs, NJ: Prentice-Hall.

AlAbdulkarim, L.O. (2013). Acceptance-by-design: elicitation of social requirements for intelligent infrastructures. Dissertation, Technische Universiteit Delft, 2013. Delft: Next Generation Infrastructures Foundation.

Alkemade, F., and Castaldi, C. (2005). Strategies for the diffusion of innovations on social networks. Computational Economics, 25(1–2): 3–23.

Allcott, H. (2011). Social norms and energy conservation. Journal of Public Economics, 95, 1082–1095.

Alolayan, B. (2014). Do I really have to accept smart fridges? An empirical study. ACHI 2014: The Seventh International Conference of Advances in Computer-Human Interactions, 186–191.

Amaral, L., Scala, A., Barthelemy, M., and Stanley, H. (2000). Classes of small-world networks. Proceedings of the National Acadamy of Sciences of the United States of America, 97(21): 11149–11152.

Armitage, C. J., and Conner, M. (2001). Efficacy of the theory of planned behaviour: A meta-analytic review. British Journal of Social Psychology, 40(4): 471–499.

Axsen, J. (2010). Interpersonal influence within car buyers' social networks: Observing consumer assessment of plug-in hybrid electric vehicles (PHEVs) and the spread of pro-societal values. Dissertation, University of California Davis.

Axsen, J., and Kurani, K.S. (2012a). Social influence, consumer behavior, and Low-carbon energy transitions. Annual Review of Environment and Resources, 37, 311–340.

Axsen, J., and Kurani, K.S. (2012b). Interpersonal influence within car buyers' social networks: applying five perspectives to plug-in hybrid vehicle drivers. Environment and Planning A, 44, 1047–1065.

Ayres, I., Raseman, S., and Shih, A. (2009). Evidence from two large field experiments that peer comparison feedback can reduce residential energy usage. NBER Working Paper No. 15386, National Bureau of Economic Research (NBER): Cambridge, MA, USA.

B.A.U.M. Consult GmbH. (2012). Smart energy made in Germany – Interim results of the E-Energy pilot projects towards the Internet of energy. http://www.e-energy.de/documents/E-Energy_Interim_results_Feb_2012.pdf

Bamberg, S. (2003). How does environmental concern influence specific environmentally related behaviors? A new answer to an old question. Journal of Environmental Psychology, 23, 21–32.

Bamberg, S., and Möser, G. (2007). Twenty years after Hines, Hungerford, and Tomera: A new meta-analysis of psycho-social determinants of pro-environmental behaviour. Journal of Environmental Psychology, 27(1): 14–25.

Bamberg, S., and Schmidt, P. (2003). Incentives, morality, or habit? Predicting students' car use for university routes with the models of Ajzen, Schwartz, and Triandis. Environment and Behavior, 35(2): 264–285.

Barabasi, A.-L. (2003). Linked: How everything is connected to everything else and what it means for business, science, and everyday life, Penguin Group, New York.

Baracaldo, N., Lopez, C., Anwar M., and Lewis, M. (2011). Simulating the effect of privacy concerns in online social networks. Proceedings IEEE International Conference on Information Reuse and Integration, Las Vegas, 3-5 August 2011, pp. 519–524.

BDEW (Bundesverband der Energie- und Wasserwirtschaft e.V.). (2015). Strompreisanalyse März 2015. Accessed 6 July 2015. http://www.germanenergyblog.de/?p=18391

Biel, A., and Thøgersen, J. (2007). Activation of social norms in social dilemmas: A review of the evidence and reflections on the implications for environmental behaviour. Journal of Economic Psychology, 28, 93–112.

BMWi (Bundesministerium für Wirtschaft und Technologie, Federal Ministry of Economics and Technology). (2012). Germany's new energy policy: Heading towards 2050 with secure, affordable and environmentally sound energy.
http://www.bmwi.de/EN/Service/publications,did=492562.html

Boehme, H. (2010). Smart Grids play key role in modern energy infrastructure, 06 September 2010, accessed 6 July 2015. http://www.dw-world.de/dw/article/0,,5978367,00.html

Bohlmann, J.D., Calantone, R.J., and Zhao, M. (2010). The effects of market network heterogeneity on innovation diffusion: An agent-based modeling approach. Journal of Product Innovation Management, 27(5): 741–760.

Bollen, K. (1989). Structural equations with latent variables. New York: Wiley.

Bollinger, B., and Gillingham, K. (2012). Peer effects in the diffusion of solar photovoltaic panels. Marketing Science, 31(6): 900–912.

Bonnes, M., Lee, T., and Bonaiuto, M. (2003). Psychological theories for environmental issues. Burlington: Vermont Ashgate Publishing Company.

Burchell, K., Rettie, R., and Patel, K. (2013). Marketing social norms: Social marketing and the 'social norm approach', Journal of Consumer Behaviour, 12, 1–9.

Byrne, B.M. (1998). Structural equation modeling with LISREL, PRELIS, and SIMPLIS. Mahhaw, NJ: Lawrence Erlbaum Associates.

Campbell, D.T. (1963). Social attitudes and other acquired behavioral dispositions. In S. Koch (Ed.), Psychology: A study of a science (Vol. 6, pp. 94-172). New York: McGraw-Hill.

Carmines, E.G., and McIver, J.P. (1981). Analyzing models with unobserved variables: Analysis of covariance structures. In G.W. Bohrnstedt & E.F. Borgatta (Eds.), Social measurement: Current issues. Beverly Hills, CA: Sage.

Choi, H., Kim, S., and Lee, J. (2010). Role of network structure and network effects in diffusion of innovations. Industrial Marketing Management, 39(1): 170–177.

Cialdini, R.B. (1993). Influence: Science and practice (3rd ed.). New York: Harper Collins.

Cialdini, R.B. (2003). Crafting normative messages to protect the environment. Current Directions in Psychological Science, 12, 105–109.

Cialdini, R.B., and Trost, M.R. (1998). Social influence: Social norms, conformity, and compliance. In D. Gilbert, S. Fiske, & G. Lindzey (Eds.), Handbook of social psychology (4th ed., Vol. 2, pp. 151–192). Boston: McGraw-Hill.

Cisco Internet Business Solutions Group (IBSG), 2008. Smart Grid: the role of electricity infrastructure in reducing greenhouse gas emissions, http://www.cisco.com/web/about/ac79/docs/Smart_Grid_FINAL.pdf

Claudy, M. (2011). An empirical investigation of consumer resistance to green product innovation. Dissertation, Dublin Institute of Technology.

Coleman, J. (1990). Foundations of social theory. Cambridge: Harvard University Press.

Condelli, L., Archer, D., Aronson, E, Curbow, B., McLeod, B., Pettigrew, T.F., White, L.T., and Yates, S. (1984). Improving utility conservation programs: Outcomes, interventions, and evaluations. Energy, 9(6): 485–494.

Davis, F.D. (1989). Perceived usefulness, perceived ease of use and user acceptance of information technology. MIS Quarterly, 13(3): 319–40.

Davis, F.D., Bagozzi, R.P., and Warshaw, P.R. (1989). User acceptance of computer technology: a comparison of two theoretical models. Management Science, 35(8): 982–1003.

Davis, F., and Venkatesh, V. (1996). A critical assessment of potential measurement biases in the technology acceptance model: Three experiments. International Journal of Human-Computer Studies, 45(1): 19–45.

De Groot, J.I.M., and Steg, L. (2010). Morality and nuclear energy: Perceptions of risks and benefits, personal norms, and willingness to take action related to nuclear energy. Risk Analysis, 30, 1363–1373.

DeCanio, S.J., Dibble, C., and Amir-Atefi, K. (2000). The importance of organizational structure for the adoption of innovations. Management Science, 46(10): 1285–1299.

Deffuant, G., Huet, S., and Amblard, F. (2005). An individual-based model of innovation diffusion mixing social value and individual benefit. American Journal of Sociology, 110(4): 1041–1069.

Delmas, M., Fischlein, M., and Asensio, O. (2013). Information strategies and energy conservation behavior: A meta-analysis of experimental studies from 1975-2011. Institute of the Environment and Sustainability, UCLA.

Delre, S.A. (2007). Effects of social networks on innovation diffusion and market dynamics. Dissertation, University of Groningen, Labyrinth Publications.

Delre, S.A., Jager, W., Bijmolt, T.H.A., and Janssen, M.A. (2007a). Targeting and timing promotional activities: An agent-based model for the takeoff of new products. Journal of Business Research, 60(8): 826–835.

Delre, S. A., Jager, W., Bijmolt, T.H.A., and Janssen, M.A. (2010). Will it spread or not? The effects of social influences and network topology on innovation diffusion. Journal of Product Innovation Management, 27, 267–282.

Delre, S. A., Jager, W., and Janssen, M.A. (2007b). Diffusion dynamics in small-world networks with heterogeneous consumers. Computational and Mathematical Organization Theory, 13(2): 185–202.

Deutsch, M., and Gerard., H. (1955). A study of normative and informational social influences upon individual judgment. Journal of Abnormal and Social Psychology, 51, 629–636.

Deutscher, I. (1966). Words and deeds: Social science and social policy. Social Problems, 13, 235–254.

Dinica, V. (2006). Support systems for the diffusion of renewable energy technologies - an investor perspective. Energy Policy, 34, 461–480.

Dünnhoff, E., and Duscha, M. (2008). Effiziente Beratungsbausteine zur Minderung des Stromverbrauchs in privaten Haushalten. Endbrericht. [Efficient consulting modules to reduce electricity consumption in private households. Final Report. Institut für Energie- und Umweltforschung, Heidelberg.

Eagly, A.H., and Chaiken, S. (1993). The psychology of attitudes. Fort Worth, Texas: Harcourt Brace Jovanovich College.

Easley, D. (2010). Networks, crowds and markets: Reasoning about a highly connected world. Cambridge University Press.

E-Energy, 2011. E-Energy Model Regions, accessed 6 July 2015. http://www.e-energy.de

Ek, K., and Söderholm Patrik, P. (2010). The devil is in the details: Household electricity saving behavior and the role of information. Energy Policy, 38(3): 1578–1587.

Elsland, R., Schlomann, B., and Eichhammer, W. (2013). Is enough electricity being saved? Impact of energy efficiency policies addressing electrical household appliances in Germany until 2030: ECEEE summer study, Presquíle de Giens, 3-8 June 2013, pp. 1651–1662.

Erdos, P., and Renyi, A. (1959). On random graphs. Publicationes mathematicae, 6, 290–297.

European Commission Smart Grid Task Force (EC SGTF), 2010. European task force for the implementation of Smart Grids into the European internal market: Mission and work programme, European Commission. https://ec.europa.eu/energy/en/topics/markets-and-consumers/smart-grids-and-meters/smart-grids-task-force

EU Commission Task Force for Smart Grids, Expert Group 1 (EU-EG1), 2010. Functionalities of smart grids and smart meters. Final deliverable, Brussels.

Faiers, A. and Neame, C. (2006). Consumer attitudes towards domestic solar power systems, Energy Policy, 34, 1797–1806.

Faiers, A., Neame, C., and Cook, M. (2007). The adoption of domestic solar-power systems: Do consumers assess product attributes in a stepwise process? Energy Policy, 35, 3418–3423.

Farhar, B, and Coburn, T. (2000). A market assessment of residential grid-tied PV system in Colorado. Boulder, Colorado: U.S. National Renewable Energy Laboratory.

Federal Energy Regulatory Commission. (2008). Assessment of demand response & advanced metering. http://www.ferc.gov/legal/staff-reports/12-08-demand-response.pdf

Fenech, T. and O'Cass, A. (2001). Internet users' adoption of Web retailing: User and product dimensions. Journal of Product & Brand Management, 10(6): 361–381.

Festinger, L. (1954). A theory of social comparison processes. Human Relations, 7, 117–140.

Festinger, L. (1964). Behavioral support for opinion change. Public Opinion Quarterly, 28, 404–417.

Fishbein, M. (2000). The role of theory in HIV prevention. AIDS Care, 12, 273–278.

Fishbein, M., and Ajzen, I. (1974). Attitudes towards objects as predictors of single and multiple behavioral criteria. Psychological Review, 81, 59–74.

Fishbein, M., and Ajzen, I. (1975). Belief, attitude, intention, and behavior: An introduction to theory and research. Reading, MA: Addison-Wesley.

Fishbein, M., and Ajzen, I. (2010).Predicting and changing behavior: The Reasoned Action Approach. New York: Taylor & Francis Group.

Gangale, F., Mengolini, A. and Onyeji, I. (2013). Consumer engagement: An insight from smart grid projects in Europe. Energy Policy, 60, 621–628.

Garay, J., and Lindholm, P. (1995). Statistics on the energy bill. Better control for the customer. In Proceedings of the seventh international energy program evaluation conference: Energy program evaluation: Uses, methods, and results, 22–25 Aug 1995, Chicago (pp. 499–504).

Gärling, T., Fujii, S., Gärling, A., and Jakobsson, C. (2003). Moderating effects of social value orientation on determinants of proenvironmental behavior intention. Journal of Environmental Psychology, 23(1): 1–9.

Geerts A. (2013). Smart meter data unlocking energy saving & load shifting potential. Changing the energy consumption behavior of consumers through smart meter data. Master thesis, Erasmus University. Available at: http://www.erim.eur.nl/centres/future-energy-business/research/master-theses/2013-anneke-geerts/

Gellings, C.W. (2009). The Smart Grid: Enabling Energy Efficiency and Demand Response. The Fairmond Press.

Gilbert, N. (2009). Agent-based models. Los Angeles: Sage.

Gilg, A., Barr, S., and Ford, N. (2005). Green consumption or sustainable lifestyles? Identifying the sustainable consumer. Futures, 37(6): 481–504.

Giordano, V., Gangale F. and Fulli, G., 2011. Smart Grids projects in Europe: Lessons learned and current developments. JRC Reference Report, EUR 24856EN, European Commission JRC (Joint Research Centre).
http://ses.jrc.ec.europa.eu/sites/ses.jrc.ec.europa.eu/files/documents/smart_grid_projects_in_europe_lessons_learned_and_current_developments.pdf

Göckeritz, S., Göckeritz, S., Schultz, P.W., Rendón, T., Cialdini, R.B., Goldstein, N.J., and Griskevicius, V. (2010). Descriptive normative beliefs and conservation behavior: The moderating roles of personal involvement and injunctive normative beliefs. European Journal of Social Psychology, 40(3): 514–523.

Godin, G., and Kok, G. (1996). The theory of planned behavior: A review of its applications to health-related behaviors. American Journal of Health Promotion, 11(2): 87–98.

Goldenberg, J., Libai, B., Solomon, S., Jan, N., and Stauffer, D. (2000). Marketing percolation. Physica A: Statistical Mechanics and its Applications, 284(1–4): 335–347.

Graziano, M., and Gillingham, K. (2014). Spatial patterns of solar photovoltaic system adoption: The influence of neighbors and the built environment. Journal of Economic Geography, pp 1–25. doi: 10.1093/jeg/lbu036

Green, B.F. (1954). Attitude measurement. In: G. Lindzey (Ed.), Handbook of social psychology (1st ed., Vol. 1, pp. 335–369). Cambridge, MA: Addison-Wesley.

Haakana, M., Sillanpää, L., & Talsi, M. (1997). The effect of feedback and focused advice on household energy consumption. Paper presented at the Summer Study of the European Council for an Energy Efficient Economy, 1997.

Hair, J., Black, W., Babin, B., Anderson, R. and Tatham, R. (2006). Multivariate data analysis. 6th edn, Pearson Education, Inc., Upper Saddle River, New Jersey.

Harland, P., Staats, H. and Wilke, A.M. (1999). Explaining proenvironmental intention and behavior by personal norms and the theory of planned behavior. Journal of Applied Social Psychology, 29, 2505–2528.

Harland, P., Staats, H. and Wilke, A.M. (2007). Situational and personality factors as direct or personal norm mediated predictors of pro-environmental behavior: Questions derived from norm-activation theory. Basic and Applied Social Psychology, 29, 323–334.

Harries, T., Rettie, R., Studley, M., Burchell, K., and Chambers, S. (2013). Is social norms marketing effective?: A case study in domestic electricity consumption. European Journal of Marketing, 47(9): 1458–1475.

Hines, J.M., Hungerford, H.R., and Tomera, A.N. (1986–87). Analysis and synthesis of research on responsible pro-environmental behavior: A meta-analysis. Journal of Environmental Education, 18(2): 1–8.

Hong, S.J., and Tam, K.Y. (2006). Understanding the adoption of multipurpose information appliances: The case of mobile data services. Information Systems Research, 17(2): 162–179.

Hovland, C.I. (1959). Reconciling conflicting results derived from experimental and survey studies of attitude change. American Psychologist, 14, 8–17.

Hoyle, R.H. (Ed.) (1995). Structural Equation Modeling: Concept, issues, and applications. Thousand Oaks, CA: Sage Publications.

Hu, L., and Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. Structural Equation Modeling, 6(1): 1−55.

Huijts, N.M.A., Molin, E.J.E. and Steg, L. (2012). Psychological factors influencing sustainable energy technology acceptance: A review-based comprehensive framework. Renewable and Sustainable Energy Reviews, 16(1): 525–531.

Jackson, T. (2005). Motivating sustainable consumption: A review of evidence on consumer behaviour and behavioural change. Guildford (UK): University of Surrey.

Jacobsson, S. and Johnson, A. (2000). The diffusion of renewable energy technology: An analytical framework and key issues for research. Energy Policy, 28, 625–640.

Jager, W. (2000). Modelling consumer behaviour. Groningen.

Jager, W. (2006). Stimulating the diffusion of photovoltaic systems: A behavioural perspective. Energy Policy, 34(14): 1935–1943.

János, L. M. (2011). Students energy saving behavior: Case study of University of Coimbra. Master thesis, University of Coimbra.

Janssen, M.A., and Jager, W. (2002). Stimulating diffusion of green products. Journal of Evolutionary Economics, 12(3): 283–306.

Jansson, J., Marell, A., and Nordlund, A. (2011). Exploring consumer adoption of a high involvement eco-innovation using value-belief-norm theory. Journal of Consumer Behaviour, 10, 51–60.

Kaiser, F., Wölfing, S., and Fuhrer, U. (1999). Environmental attitude and ecological behavior. Journal of Environmental Psychology, 19(1): 1-19.

Kaufmann, P., Stagl, S., and Franks, D.W. (2009). Simulating the diffusion of organic farming practices in two new EU member states. Ecological Economics, 68(10): 2580–2593.

Keirstead, J. (2006). Behaivoural responses to photovoltaic systems in the UK domestic sector. Environmental Change Institute, University of Oxford.

Keirstead, J. (2007). Behavioural responses to photovoltaic systems in the UK domestic sector. Energy Policy, 35(8): 4128–4141.

Kiesling, E., Günther, M., Stummer, C., and Wakolbinger, L.M. (2012). Agent-based simulation of innovation diffusion: A review. Central European Journal of Operations Research, 20(2): 183–230.

Kelman, H.C. (1974). Attitudes are alive and well and gainfully employed in the sphere of action. American Psychologist, 29, 310-324.

Kim, S., Lee, K., Cho, J.K., and Kim, C.O. (2011). Agent-based diffusion model for an automobile market with fuzzy TOPSIS-based product adoption process. Expert Systems with Applications, 38(6): 7270–7276.

King, W. R. and He, J. (2006). A meta-analysis of the technology acceptance model, Information & Management, 43(6): 740–755.

Kline, R.B. (2005). Principles and practice of structural equation modeling (2nd ed.). New York: Guilford.

Kocsis, G., and Kun, F. (2008). The effect of network topologies on the spreading of technological developments. Journal of Statistical Mechanics: Theory and Experiment, (10): 10014.

Kranz, J., Gallenkamp, J. and Picot, A. (2010). Power control to the people? Private consumers' acceptance of Smart Meters. South Africa: Proceedings of the 18th European Conference on Information Systems (ECIS).

Kranz, J. and Picot, A. (2011). Why are consumers going green? The role of environmental concerns in private Green-IS adoption. ECIS 2011 Proceedings, Paper 104.

Kranz, J. and Picot, A. (2012). Is it money or the environment? An empirical analysis of factors influencing consumers' intention to adopt the Smart Metering Technology. Proceedings of the 18th American Conference on Information Systems (AMCIS), Seattle (USA), 9-11 August 2012.

Kröger, W., and Zio, E. (2011). Vulnerable systems, Springer.

Kuandykov, L., and Sokolov, M. (2010). Impact of social neighborhood on diffusion of innovation S-curve. Decision Support Systems, 48(4): 531–535.

Kunegis, J. (2011). On the spectral evolution of large networks. PhD thesis, University of Koblenz–Landau.

Kurahashi, S. and Saito, M. (2011). Word-of-Mouth effects on social networks. Knowledge-Based and Intelligent Information and Engineering Systems, Lecture Notes in Computer Science, 6883: 356–365.

Kwan, C.L. (2012). Influence of local environmental, social, economic and political variables on the spatial distribution of residential solar PV arrays across the United States. Energy Policy, 47, 332–344.

Labay, D.G., and Kinnear, T.C. (1981). Exploring the consumer decision process in the adoption of solar energy. Journal of Consumer Research, 8, 271–278.

LaPiere, R.T. (1934). Attitudes vs. actions. Social forces, 13, 230–237.

Latané, B. (1981). The psychology of social impact, American Psychologist, 36, 343–356.

Leenheer, J., de Nooij, M., and Sheikh, O. (2011). Own power:  Motives of having electricity without the energy company. Energy Policy, 39, 5621–5629.

Liska, A.E. (1990). The significance of aggregate dependent variables and contextual independent variables for linking macro and micro theories. Social Psychology Quarterly, 53(4): 292–301.

Loock, C.-M., Staake, T., and Landwehr, J. (2011). Green IS design and energy conservation: A new empirical investigation of social normative feedback. 32nd International Conference on Information Systems, Shanghai.

Loock, C.-M., Staake, T., Landwehr, J., Fleisch, E. and Pentland, A. (2012). The influence of reference frame and population density on the effectiveness of social normative feedback on electricity consumption. 33rd International Conference on Information Systems, Orlando.

McDonald, R.P. and Ringo Ho, M.-H. (2002). Principles and practice in reporting structural equation analyses. Psychological Methods, 7(1): 64-82.

Melynk, V., van Herpen, E., and van Trijp, H.C.M. (2010). The influence of social norms in consumer behavior: A meta-analysis. Advances in Consumer Research, Association for Consumer Research.

Mengolini, A., and Vasiljevska, J. (2013). The social dimension of Smart Grids. Consumer, community, society, JRC Scientific and Policy Report. http://ses.jrc.ec.europa.eu/sites/ses.jrc.ec.europa.eu/files/documents/the_social_dimension_of_smart_grids.pdf

Mi, L., Nie, R., Li, H., and Li, X. (2011). Empirical research of social norms affecting urban residents low carbon energy consumption behavior. Energy Procedia, 5, 229–234.

Midden, C.J.H. and Huijts, N.M.A. (2009). The role of trust in the affective evaluation of novel risks: The case of CO2 storage. Risk Analysis, 29(5): 743–751.

Mills, B. and Schleich, J. (2010). What's driving energy-efficient appliance label awareness and purchase propensity? Energy Policy, 38(2): 814–825.

Montijn-Dorgelo, F. and Midden, C.J.H. (2008). The role of negative associations and trust in risk perception of new hydrogen systems. Journal of risk research, 11: 659-671.

Moss, S.J., and Cubed, M. (2008). Market segmentation and energy efficiency program design. California Institute for Energy and Environment.

Müller, S., and Rode, J. (2013). The adoption of Photovoltaic systems in Wiesbaden, Germany. Economics of Innovation and New Technology, 22(5): 519–535.

Nachtigall, C., Kroehne, U., Funke, F., and Steyer, R. (2003). (Why) should we use SEM? Pros and cons of structural equation modeling. Methods of Psychological Research Online, 8, 1–22.

Newman, M.E.J. (2001). Scientific collaboration networks. II. Shortest paths, weighted networks, and centrality. Physical Review E, 64(1): 016132.

Ngar-yin Mah, D., Van der Vleuten, J.M., Chi-man, Ip, J., and Ronald Hills, P. (2012). Governing the transition of socio-technical systems: A case study of the development of smart grids in Korea. Energy Policy, 45, 133–141.

Nolan, J.M., Schultz, P.W., Cialdini, R.B., Goldstein, N.J., and Griskevicius, V. (2008). Normative social influence is underdetected. Personality and Social Psychology Bulletin, 34(7): 913–923.

Nordlund, A.M. and Garvill, J. (2002). Value structure behind proenvironmental behavior. Environment and Behavior, 34, 740–756.

Notani, A. S. (1998). Moderators of perceived behavioral control's predictiveness in the theory of planned behavior: A meta-analysis. Journal of Consumer Psychology, 7(3): 247-271.

Oliver, P.E., Marwell, G., and Teixeira, R. (1985). A theory of the critical mass. I. Interdependence, group heterogeneity, and the production of collective action. American journal of Sociology, 91, 522–556.

Painuly, J. P. (2001). Barriers to renewable energy penetration: A framework for analysis. Renewable Energy, 24, 73–89.

Peschiera, G., and Taylor, J.E. (2012). The impact of peer network position on electricity consumption in building occupant networks utilizing energy feedback systems. Energy and Buildings, 49, 584–590.

Peschiera, G., Taylor, J.E., and Siegel, J.A. (2010). Response–relapse patterns of building occupant electricity consumption following exposure to personal, contextualized and occupant peer network utilization data. Energy and Buildings, 42(8): 1329–1336.

Petersen, J.E., Shunturov, V., Janda, K., Platt, G., and Weinberger, K. (2007). Dormitory residents reduce electricity consumption when exposed to real-time visual feedback and incentives. International Journal of Sustainability in Higher Education, 8(1): 16–33.

Petkov, P., Foth, M., Köbler, F., and Krcmar, H. (2011). Motivating domestic energy conservation through comparative, community-based feedback in mobile and social media. 5th International Conference on Communities & Technologies (C&T 2011), 29 June–2 July 2011, Brisbane.

Poortinga, W., Pidgeon, N., and Lorenzioni, I. (2006). Public perceptions of nuclear power, climate change and energy options in Britain: Summary of findings of a survey conducted during October and November 2005. School of Environmental Science, University of East Anglia.

Poortinga, W., Steg, L., and Vlek, C. (2004). Values, environmental concern, and environmental behavior: A study into household energy use. Environment and Behavior, 36(1): 70–93.

Poortinga, W., Steg, L., Vlek, C., and Wiersma, G. (2003). Household preferences for energy-saving measures: a conjoint analysis. Journal of Economic Psychology, 24(1): 49–64.

Rahmandad, H., and Sterman, J. (2008). Heterogeneity and network structure in the dynamics of diffusion: Comparing agent-based and differential equation models. Management Science, 54(5): 998–1014.

Reddy, S. and Painuly, J.P. (2004). Diffusion of renewable energy technologies - barriers and stakeholders' perspectives. Renewable Energy, 29, 1431–1447.

Rettie, R., Burchell, K., and Harries, T. (2013). CHARM research summary 6: The CHARM social norms approach. Behaviour and Practice Research Group, Kingston University. Available at http://www.projectcharm.info/

Rhein, E., 2010. Germany defines sustainable energy policy up to 2050, 13 September 2010, accessed 6 July 2015. http://rhein.blogactiv.eu/2010/09/13/germany-defines-sustainable-energy-policy-up-to-2050/

Richter, L.-L. (2014). Social effects in the diffusion of solar photovoltaic technology in the UK. EPRG Working Paper 1332.

Roberts, J.A. (1996). Green consumers in the 1990s: Profile and implications for advertising. Journal of Business Research, 36(3): 217–231.

Rode, J., and A. Weber (2012). Does localized imitation drive technology diffusion? A case study on solar cells in Germany. Working paper.

Rogers, E.M. (1983). Diffusion of innovations (3rd ed.). New York: Free Press.

Rothfield, E. (2010). Solar photovoltaic installation in California: Understanding the likelihood of adoption given incentives, electricity pricing and consumer characteristics. Duke University.

RWI (Rheinisch-Westfälisches Instituts für Wirtschaftsforschung) and forsa Gesellschaft für Sozialforschung und statistische Analysen mbH (2011). Erhebung des Energieverbrauchs der privaten Haushalte für die Jahre 2006-2008.

Sawyer, S.W. (1982). Leaders in change: Solar energy owners and the implications for future adoption rates. Technological Forecasting and Social Change, 21, 201-211.

Schepers, J. and Wetzels, M. (2007). A meta-analysis of the technology acceptance model: Investigating subjective norm and moderation effects. Information & Management, 44(1): 90–103.

Schot, V. (2011). Social norms to motivate IT use. Master thesis, School of Management and Governance, University of Twente.

Schultz, P.W., Nolan, J.M., Cialdini, R.B., Goldstein, N.J., and Griskevicius, V. (2007). The constructive, destructive, and reconstructive power of social norms. Psychological Science, 18(5): 429-434.

Schultz, P.W., Tabanico, J., and Rendo´n, T. (2008). Normative beliefs as agents of influence: Basic processes and real-world applications. In R. Prislin, & W. Crano (Eds.), Attitudes and persuasion. New York: Psychology Press.

Schumacker, R.E. and Lomax, R.G. (1996). A beginner's guide to Structural Equation Modelling. Lawerence Erbaum, Mahwah, New Jersey.

Schuman, H., and Johnson, M.P. (1976). Attitudes and behavior. Annual Review of Sociology, 2, 161–207.

Schwartz, S.H. (1977). Normative influences on altruism. In B. Leonard (Ed.), Advances in experimental social psychology: Academic Press.

Schwarz, N., and Ernst, A. (2009). Agent-based modeling of the diffusion of environmental innovations: An empirical approach. Technological Forecasting and Social Change, 76(4): 497–511.

Sernhed, K., Pyrko, J., and Abaravicius, J. (2003). Bill me this way!—customer preferences regarding electricity bills in Sweden. In Proceedings of the 2003 summer study of the European Council for an energy efficient economy (pp. 1147–1150). Stockholm: ECEEE.

Siegrist, M., and Cvetkovich, G. (2000). Perception of hazards: The role of social trust and knowledge. Risk Analysis, 20(5): 713-719.

Steg, L., Dreijerink, L., and Abrahamse, W. (2005). Factors influencing the acceptability of energy policies: A test of VBN theory. Journal of Environmental Psychology, 25(4): 415–425.

Stern, P.C. (2000). Toward a coherent theory of environmentally significant behavior. Journal of Social Issues, 56(3): 407–424.

Stern, P., Dietz, T., Abel, T., Guagnano, G., and Kalof, L. (1999). A Value-Belief Norm theory of support for social movements: The case of environmental concern. Human Ecology Review, 6, 81–97.

Stokes, L. C., Mildenberger, M., Savan, B., and Kolenda, B. (2012). Analyzing barriers to energy conservation in residences and offices: The Rewire Program at the University of Toronto. Applied Environmental Education and Communication, 11, 88–98.

Stragier, J., Hauttekeete, L., and De Marez, L. (2010). Introducing smart grids in residential contexts: Consumers' Perception of Smart Household Appliances. 2010 IEEE Conference on Innovative Technologies for an Efficient and Reliable Electricity Supply, CITRES 2010, 135–142.

Strang, S.J. (2014). Network analysis in criminal intelligence. In A.J. Masys (Ed.), Networks and network analysis for defence and security. Series: Lecture Notes in Social Networks, Springer International Publishing.

Sütterlin, B., Brunner, T.A., and Siegrist, M. (2011). Who puts the most energy into energy conservation? A segmentation of energy consumers based on energy-related behavioral characteristics. Energy Policy, 39(12): 8137–8152.

Tabachnick, B.G., and Fidell, L.S. (2007). Using multivariate statistics (5th ed.). Upper Saddle River, NJ: Pearson Allyn & Bacon.

Tanford, S. and Penrod, S. (1984). Social influence model: A formal integration of research on majority and minority influence processes, Psychological Bulletin, 95, 189-225.

Thacker, J. W., Fields, M. W., and Tetrick, L. E. (1989). The factor structure of union commitment: An application of confirmatory factor analysis. Journal of Applied Psychology, 74, 228232.

Thiriot, S., and Kant, J.D. (2008). Using associative networks to represent adopters' beliefs in a multiagent model of innovation diffusion. Advances in Complex Systems, 11(2): 261–272.

Thøgersen J. (1996). Recycling and morality: A critical review of the literature. Environment and Behavior, 28, 536–558.

Thøgersen, J., and Grønhøj, A. (2010). Electricity saving in households—A social cognitive approach. Energy Policy, 38(12): 7732–7743.

Timpe, C. (2009). Smart domestic appliances supporting the system integration of Renewable Energy. Report of the European project "Smart Domestic Appliances in Sustainable Energy Systems (Smart-A)".

Toft, M.B. (2014). Consumer adoption of sustainable energy technology—the case of smart grid technology. Dissertation, Aarhus University.

Toft, M.B., Schuitema, G. and Thøgersen, J. (2014). Responsible technology acceptance: Model development and application to consumer acceptance of Smart Grid technology. Applied Energy, 134(1): 392–400.

Toft, M.B. and Thøgersen, J. (2015). Exploring private consumers' willingness to adopt Smart Grid technology. International Journal of Consumer Studies, 39(6): 648–660.

Ueno, T., Inada, R., Saeki, O., and Tsuji, K. (2005). Effectiveness of displaying energy consumption data in residential houses. Analysis on how the residents respond. In Proceedings of the 2005 summer study of the European Council for an energy efficient economy (pp. 1289–1299). Stockholm: ECEEE.

Valente, T.W., and Davis, R.L. (1999). Accelerating the diffusion of innovations using opinion leaders. The Annals of the American Academy of Political and Social Science, 566(1): 55–67.

Valente, T.W., and Schuster, D.V. (2002). The public health perspective for communicating environmental issues. In: Dietz T, Stern PC. New Tools for Environmental Protection: Education, Information and Voluntary Measures. Washington, DC: National Academy Press.

Valocchi, M., Juliano, J., and Schurr, A. (2009). Lighting the way—understanding the smart energy consumer. IBM Global Services.

Venkatesh,V., and Davis, F.D. (2000). A theoretical extension of the technology acceptance model: four longitudinal field studies. Management Science, 46(2): 186–204.

Venkatesh, V., and Morris, M. (2000). Why don't men ever stop to ask for directions? Gender, social influence, and their role in technology acceptance and user behavior. MIS Quarterly, 24, 115–139.

Venkatesh, V., Morris, M.G., Davis, G.B. and Davis, F.D. (2003). User acceptance of information technology: Towards a unified view. MIS Quarterly, 27(3): 425–478.

Venkatesh, V., and Brown, S. (2001). A longitudinal investigation of personal computers in homes: Adoption determinants and emerging challenges. MIS Quarterly, 25(1): 71–102.

Venkatesh, V., Thong, J.Y.L., and Xu, X. (2012). Consumer acceptance and use of Information Technology: Extending the Unified Theory of Acceptance and Use of Technology. MIS Quarterly, 36(1): 157–178.

Watts, D.J. and Strogatz, S.H. (1998). Collective dynamics of 'small-world' networks. Nature, 393(6684): 440–442.

Weigel, F.K., Hazen, B.T., Cegielski, C.G., and Hall, D.J. (2014). Diffusion of Innovations and the Theory of Planned Behavior in Information Systems Research: A Metaanalysis. Communications of the Association for Information Systems, 34(1): 619-636.

Welsch, H. and Kühling, J. (2009). Determinants of pro-environmental consumption: The role of reference groups and routine behavior. Ecological Economics, 69(1): 166–176.

Wicker, A.W. (1969). Attitudes versus actions: The relationship of verbal and overt behavioral responses to attitude objects. Journal of Social Issues, 25(4): 41–78.

Wilhite, H., Høivik, A., and Olsen, J.-G. (1999). Advances in the use of consumption feedback information in energy billing: The experiences of a Norwegian energy utility. Paper presented at the Summer Study of the European Council for an Energy Efficient Economy, 1999, paper no. 3-2.

Wilson, C., Pettifor, H., and McCollum, D. (2014). Improving the behavioural realism of integrated assessment models of global climate change mitigation: a research agenda. ADVANCE Project Deliverable No. 3.2. Tyndall Centre for Climate Change Research, Norwich, UK and International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Wilson, C., and Dowlatabadi, H. (2007). Models of decision making and residential energy use. Annual Review of Environment and Resources, 32, 169–203.

Wolsink, M. (2012). The research agenda on social acceptance of distributed generation in smart grids: Renewable as common pool resources. Renewable and Sustainable Energy Reviews, 16(1): 822–835.

Zhang, T., and Nuttall, W.J. (2011). Evaluating government's policies on promoting smart metering diffusion in retail electricity markets via agent-based simulation. Journal of Product Innovation Management, 28(2): 169–186.

# Appendix:

## Coding sheet

## &

## the original questionnaire (in German)

## Coding sheet

## Section I: Electricity consumption

V1. Household electricity consumption depends on many factors, please fill out your situation.

V1a. How many people aged 18 or older are living in your household, including yourself?

V1b. How many people under 18 are living in your household?

V1c. Please estimate the monthly electricity cost of your household.

V2. Would you like to be regularly informed about your electricity consumption, with electricity cost and tips to save electricity?

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Yes, every week | 2 | Yes, every month | 3 | Yes, 6-8 times each year | 4 | Yes, 3-4 times each year | 5 | No |

V3. Please choose the appliances you own at home (more options possible):

❑Refrigerator ❑Projector ❑Electric stove
❑Washing machine ❑DVD player ❑Bake oven
❑Tumble dryer ❑Playstation/Xbox/Wii ❑Microwave
❑Dishwasher ❑Computer ❑Coffee machine ❑Electric heating

V4. Smart appliances can be automatically controlled by the electricity price signal, thereby reducing electricity cost.

Can you imagine using the following appliances? They can be switched to manual operation mode as well.

| **Appliance** | **1=Yes** | **2=No** | **99=no idea** |
|---|---|---|---|
| Bake oven | ❑ | ❑ | ❑ |
| Washing machine | ❑ | ❑ | ❑ |
| Tumble dryer | ❑ | ❑ | ❑ |
| Dishwasher | ❑ | ❑ | ❑ |
| Electric heating | ❑ | ❑ | ❑ |

V5. Have you been informed about potentials of electricity saving?

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Yes, very often | 2 | Yes, often | 3 | Yes, occasionally | 4 | Yes, seldom | 5 | No, never |

V6. Please choose the information source you have used (more options possible):

❑newspaper ❑professional journals ❑TV/Radio ❑Internet ❑brochure ❑craftsman
❑information event ❑personal consultation ❑Others

V7. Please choose the one which fits your situation.

| **Code** | | **1=is absolutely true** | **2=is quite true** | **3=is partially true** | **4=is hardly true** | **5=is not true at all** | **99=don't know** |
|---|---|---|---|---|---|---|---|

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| V7a | I usually remember to turn lights off when I leave the room. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V7b | I usually leave the computer on even when I will not use it for a long time. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V7c | If possible I will prefer hanging clothes out to using the dryer. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V7d | I leave appliances in Standby mode when they aren't needed for long. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V7e | I pay much attention to whenever possible I could save electricity at home. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |

V8. Please think about each statement below and choose which fits your opinion best.

| **Code** | | **1=is absolutely true** | **2=is quite true** | **3=is partially true** | **4=is hardly true** | **5=is not true at all** | **99=don't know** |
|---|---|---|---|---|---|---|---|
| V8a | As long as big companies consume so much electricity as always, I don't think I should save electricity. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V8b | Whether I consumer some less or more electricity, it makes no different impact on the environment. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V8c | Most of the people who are important to me (e.g., friends/family, neighbors) think that I should save electricity. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V8d | It will be easy to reduce my electricity consumption by 10%. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V8e | If I have more information about my electricity use, I am likely to consume less. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |

## Section II: Smart grid

Here is an explanation of smart grid in case you do not know the term:

Smart grid is an electricity network that can cost efficiently integrate the actions of all users connected to it– generators, consumers and those that do both –in order to balance supply and demand. Managing home appliances of consumers is one of the important means.

V9. In the past have you been informed about the topics “Energiewende” and “Smart grid”?

| | 1=Yes, very often | 2=Yes, often | 3=Yes, occasionally | 4=Yes, seldom | 5=No, never |
|---|---|---|---|---|---|
| V9a. Energiewende | ❑ | ❑ | ❑ | ❑ | ❑ |
| V9b. Smart grid | ❑ | ❑ | ❑ | ❑ | ❑ |

V10. Please choose the information source you have used (more options possible):
❑newspaper ❑professional journals ❑TV/Radio ❑Internet ❑brochure ❑craftsman
❑information event ❑personal consultation ❑Others

V11. Below are some questions about Energiewende. Please choose which fits your opinion best.

| **Code** | | **1=is absolutely true** | **2=is quite true** | **3=is partially true** | **4=is hardly true** | **5=is not true at all** | **99=don’t know** |
|---|---|---|---|---|---|---|---|
| V11a | The advantages and disadvantages of Energiewende are clear to me. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V11b | I have no idea what Energiewende brings to me. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V11c | I would like to support the aims of Energiewende. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |

V12. Below are some questions about smart grid. Please choose which fits your opinion best.

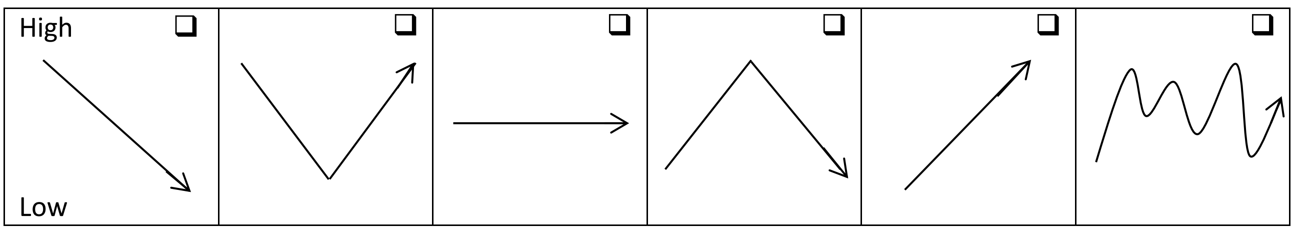
| **Code** | | **1=is absolutely true** | **2=is quite true** | **3=is partially true** | **4=is hardly true** | **5=is not true at all** | **99=don’t know** |
|---|---|---|---|---|---|---|---|
| V12a | The advantages and disadvantages of smart grid are clear to me. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V12b | Smart grid will not be realized in Germany. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V12c | If my electricity supplier makes it possible for me to participate in smart grid applications, I will be very likely to take part. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V12d | Most of the people who are important to me (e.g., friends/family, neighbors) think that it is good that I | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | support smart grid. | | | | | | |
| V12e | I support smart grid implementation because it contributes to the sustainable society. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V12f | I am against smart grid implementation because the costs are too high. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V12g | I am against smart grid implementation because I need to allow electricity suppliers to control my consumption. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |

V13. Do you use a smart meter (a device with feedback of your electricity consumption)?

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | Yes | 2 | No, but has planned | 3 | No | 99 | Don’t know |

V14. Which figure fits your opinion best about the future development of electricity price in Germany?




V15. Please assume if there is no Energiewende and we would continue using oil, gas, coal and nuclear power to generate electricity. Which figure above will you choose then about the future development of electricity price?

V16. Will the Energiewende influence the branch you work in, positively or negatively?

| | | | | | |
|---|---|---|---|---|---|
| 1 | Very negatively | 2 | Negatively | 3 | Neither negatively nor positively |
| 4 | Positively | 5 | Very positively | 99 | Don’t know |

V17. Which branch do you work in?

V18. Under no wind and no sunshine circumstances, which options dealing with the energy demand do you prefer? Please rate on a scale of 0-10, the higher, the more you prefer. Rating 0 means complete rejection.

| Option |
|---|
| Energy import from other countries |
| Fossil energy (oil, gas, coal) |
| Large central energy storage |
| Small decentral energy storage |
| Reduction of electricity consumption when electricity price is very high (e.g., at peak hours) |

| |
|---|
| Reduction of electricity consumption through contracts of agreeing to shut down energy intensive appliances at peak hours |
| Reducing a predetermined maximum quantity of electricity at peak hours |

V19. Please choose the top 3 options you accept the most? Please mark “1” for your first choice, “2” for your second choice and “3” for your third choice.

| Option |
|---|
| Energy import from other countries |
| Fossil energy (oil, gas, coal) |
| Large central energy storage |
| Small decentral energy storage |
| Reduction of electricity consumption when electricity price is very high (e.g., at peak hours) |
| Reduction of electricity consumption through contracts of agreeing to shut down energy intensive appliances at peak hours |
| Reducing a predetermined maximum quantity of electricity at peak hours |

V20. Below are three kinds of tariffs dealing with limited electricity supply under no wind or no sunshine circumstances. Please consider whether they are possible options for you to be involved in reducing load on the grid and choose which fits your opinion best.

| | **1=not possible at all** | **2=not possible** | **3= un decided** | **4= possible** | **5=very possible** | **99= don’t know** |
|---|---|---|---|---|---|---|
| A kind of electricity tariff: when there is little power available, the price goes very high; when there is a lot of power available, the price becomes very low. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| A kind of electricity tariff: when there is little power available, it allows the installed home storage to provide electricity for basic needs such as lighting, fridge and freezer. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| A kind of electricity tariff: when there is little power available, your home electricity will be cut off for maximum 2 hours. For each hour out of electricity you will receive 10% rebate of your electricity costs for that month. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |

V21. How much do you trust your current electricity providers to handle the consumption data?

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | A great deal | 2 | Much | 3 | Moderate | 4 | A little | 5 | Very little | 99 | don’t know |

V22. Do you agree that the electricity providers gather your electricity consumption data to help balance supply and demand?

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Completely agree | 2 | Agree | 3 | Undecided | 4 | Disagree | 5 | Completely disagree | 99 | don't know |

V23. Please choose the electricity provider you are using.

V24. Are you using green electricity?

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | Yes | 2 | Partially | 3 | No | 99 | don't know |

## Section III: Energy efficiency

V25. Have you ever seen this graph (Energy label) on electric appliances?

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Yes, very often | 2 | Yes, often | 3 | Yes, occasionally | 4 | Yes, seldom | 5 | No, never |

V26. What type of TV do you have (more options possible)?
❑Plasma TV ❑LCD/LED TV ❑Standard CRT TV
❑Computer with TV card ❑No TV ❑don't know

V27. Please choose max. 2 kinds of bulbs used often in you rooms.
❑Conventional light bulbs ❑Halogen bulbs ❑Energy saving bulbs ❑LED bulbs ❑Mixture

V28. Please estimate how often you use the following appliances and fill in your use frequency (unit: number of times per week).
For example, if you use bake oven 1 time per 2 weeks, you can fill in 0.5.
If you do not know the frequency of an appliance, you can skip the question.

Washing machine___________
Tumble dryer___________
Dishwasher___________
Electric stove___________
Bake oven___________

V29. Please choose the one which fits your situation.

| **Code** | **When using an appliance, I usually** | **1=is absolutely true** | **2=is quite true** | **3=is partially true** | **4=is hardly true** | **5=is not true at all** | **99= don't know** | **97= don't have** |
|---|---|---|---|---|---|---|---|---|
| V29a | use eco program of the washing machine | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V29b | use eco program of the dishwasher | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V29c | use power saving mode of the computer | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V29d | complete shutdown of | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | appliances like TV and DVD player when not using for a long time | | | | | | | |

V30. Please think about each statement below and choose which fits your opinion best.

| **Code** | | **1=is absolutely true** | **2=is quite true** | **3=is partially true** | **4=is hardly true** | **5=is not true at all** | **99=don't know** |
|---|---|---|---|---|---|---|---|
| V30a | When buying an appliance, its electricity consumption is very important to me. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V30b | Price of the appliance is more important than its electricity consumption to me. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V30c | If there are favorable financing or rebates for the purchase of energy efficient appliances, I would like to buy one. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V30d | Before I spend money on an efficient appliance, I would like to know more about its benefits. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V30e | I will purchase energy efficient appliances, because it saves money in the long term. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V30f | I will purchase energy efficient appliances, because protecting the environment is very important to me. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |

## Section IV. Renewable energies and electricity production

V31. If a new wind park will be built about 10 km away from where you live, you will:

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Disagree strongly | 2 | Disagree | 3 | Undecided | 4 | Agree | 5 | Agree strongly | 98 | don't care |

V32. If a large-scale solar system will be installed about 10 km away from where you live, you will:

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Disagree strongly | 2 | Disagree | 3 | Undecided | 4 | Agree | 5 | Agree strongly | 98 | don't care |

V33. Have you been informed about home installations of renewable energies?

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Yes, very often | 2 | Yes, often | 3 | Yes, occasionally | 4 | Yes, seldom | 5 | No, never |

V34. Please choose the information source you used for this (more options possible):
❑newspaper ❑professional journals ❑TV/Radio ❑Internet ❑brochure ❑craftsman
❑information event ❑personal consultation ❑Others

V35. Please choose the one which fits your experience about wind turbines.

| **Code** | | **1=Yes** | **2=No** | **99=don't know** |
|---|---|---|---|---|
| V35a | Near my living place there are wind energy facilities. | ❑ | ❑ | ❑ |
| V35b | I know people who are involved in the construction and operation of wind turbines. | ❑ | ❑ | ❑ |
| V35c | I/My family have/has invested in wind energy facilities. | ❑ | ❑ | ❑ |

V36. Please choose the one which fits your experience about solar systems for electricity generation.

| **Code** | | **1=Yes** | **2=No** | **99=don't know** |
|---|---|---|---|---|
| V36a | Near my living place there are solar energy facilities. | ❑ | ❑ | ❑ |
| V36b | I know people who have installed a rooftop solar system. | ❑ | ❑ | ❑ |
| V36c | I/My family have/has invested in solar cells. | ❑ | ❑ | ❑ |

V37. Are you a home owner or a renter?

| | | | |
|---|---|---|---|
| 1 | Owner | 2 | Renter |

V38. If possible, can you imagine having a rooftop solar system installed?

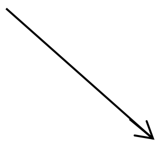
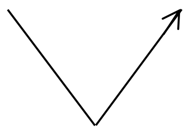
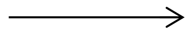
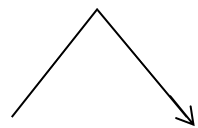
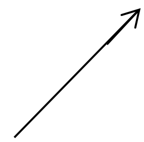
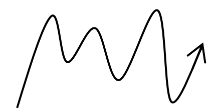
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | Yes | 2 | Maybe | 3 | No | 99 | don't know |

V39. Please choose the one which fits your opinion about applying home photovoltaics for electricity generation. I think it is:

| **Code** | | **1=is absolutely true** | **2=is quite true** | **3=is partially true** | **4=is hardly true** | **5=is not true at all** | **99=don't know** |
|---|---|---|---|---|---|---|---|
| V39a | Too expensive | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V39b | Harm the environment | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V39c | Ugly | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V39d | Modern | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V39e | Reliable | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| V39f | Maintenance-intensive | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V39g | Independent from electricity supplier | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V39h | Worthwhile investment | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |

V40. Which figure fits your opinion best about the future price development of photovoltaics in Germany?

| | | | | | |
|---|---|---|---|---|---|
| High ❑  Low | ❑  | ❑  | ❑  | ❑  | ❑  |

V41. What do you think the payback period for a rooftop PV system would be?

| | | | | | |
|---|---|---|---|---|---|
| 1 | Less than 5 years | 2 | 5-10 years | 3 | 11-15 years |
| 4 | 16-20 years | 5 | 21 years and more | 6 | Never |

V42. Please choose the one which fits your opinion about applying photovoltaics.

| **Code** | | **1=is absolutely true** | **2=is quite true** | **3=is partially true** | **4=is hardly true** | **5=is not true at all** | **99=don't know** |
|---|---|---|---|---|---|---|---|
| V42a | I believe in future photovoltaics will be everywhere in Germany. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V42b | Most of the people who are important to me (e.g., friends/family, neighbors) think that it is good that I install a PV system. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| V42c | I would recommend friends and acquaintances to install a rooftop PV system. | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |

## Section V. About yourself

V43. In which year were you born? ___________

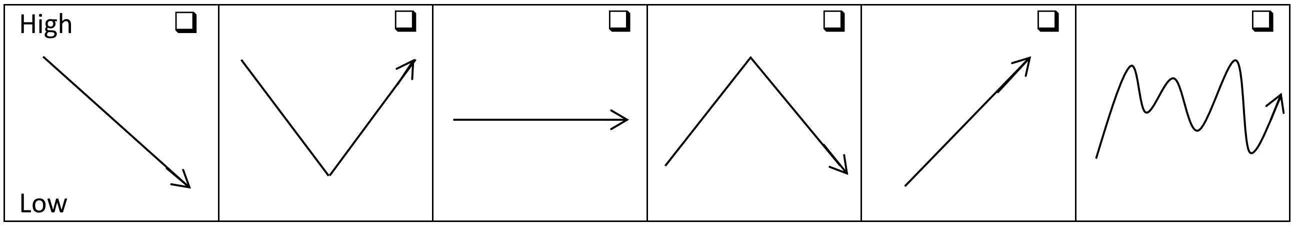
V44. You are:

| | | | |
|---|---|---|---|
| 1 | male | 0 | female |

V45. What is the highest degree or level of school you have completed? If currently enrolled, please mark the previous grade or highest degree you have received.

V46. Please estimate your net household income per month.

V47. Which figure fits your opinion best about the future development of your income?




V48. Please fill in the first 3 numbers of your zip code, so we could have an idea of your living region. ___________

## Willkommen

# Wissenschaftliche Umfrage zum individuellen Energieverbrauch

Sehr geehrte Teilnehmerin, sehr geehrter Teilnehmer,

herzlichen Dank für Ihre Bereitschaft, an unserer Umfrage teilzunehmen!
Die Energiewende in Deutschland ist ein Schwerpunkt unseres Forschungsteams an der Universität Stuttgart. Zu Ihrer Umsetzung sind nicht nur technische Entwicklungen wie z.B. sparsame Geräte, Photovoltaik- und Windkraftanlagen, und neue, intelligente gesteuerte Stromnetze erforderlich, sondern auch Veränderungen in den Konsumgewohnheiten. Deshalb möchten wir Sie gerne fragen, wie Sie Energie heute oder in Zukunft nutzen.

### Hinweise zum Ausfüllen des Fragebogens

-Wenn Sie eine Frage nicht beantworten möchten, können Sie diese Frage einfach überspringen.

-Es gibt keine falschen oder richtigen Antworten.

-Bitte antworten Sie spontan.

Für das Ausfüllen des Fragebogens benötigen Sie ca. 15-20 Minuten.

### Datenschutzerklärung

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**Vielen Dank für Ihre Unterstützung unseres Forschungsprojektes!**

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70174 Stuttgart

## I – Stromverbrauch

## 1. Der Stromverbrauch eines Haushalts ist von vielen Einflussgrößen abhängig. Wie ist dies bei Ihnen?

Wie viele Personen, die 18 Jahre oder älter sind, leben in Ihrem Haushalt?

Wie viele Personen unter 18 Jahren leben in Ihrem Haushalt?

Bitte schätzen Sie, wie viel Geld Sie derzeit für Strom rechnung im Monat ausgeben? Ungefähr (in Euro)

## 2. Hätten Sie gerne mehr regelmäßige Informationen über Ihren Stromverbrauch, die damit verbundenen Kosten und Tipps zum Stromsparen?

- Ja, wöchentlich
- Ja, monatlich
- Ja, 6-8 mal im Jahr
- Ja, 3-4 mal im Jahr
- Nein

## 3. Bitte wählen Sie alle Geräte, die Sie zu Hause nutzen (Mehrfachnennung möglich):

- Kühlschrank
- Waschmaschine
- Wäschetrockner
- Geschirrspülmaschine
- Elektroheizung
- Beamer
- Blu-ray/DVD-player
- PlayStation/ Xbox/Wii
- Computer/PC
- Kaffeemaschine
- Elektroherd
- Backofen
- Mikrowelle

**4. Inzwischen gibt es elektronische Steuerungen, die selbständig Elektrogeräte einschalten, wenn die Strompreise sehr niedrig sind, und diese abschalten, wenn der Strompreis besonders hoch ist.**
**Dadurch könnten Sie erheblich Stromkosten sparen.**

**Bei welchen der folgenden Geräte könnten Sie sich vorstellen, diese Möglichkeit des Stromsparens zu nutzen?**
**Natürlich können Sie die Geräte auch stets per Hand ein- und ausschalten, wenn es Ihnen gerade nicht passt.**

| | Ja | Nein | **weiß nicht** |
|---|---|---|---|
| Backofen | ○ | ○ | ○ |
| Waschmaschine | ○ | ○ | ○ |
| Wäschetrockner | ○ | ○ | ○ |
| Geschirrspülmaschine | ○ | ○ | ○ |
| Elektroheizung | ○ | ○ | ○ |

**5. Haben Sie sich schon über Möglichkeiten, Strom zu sparen, informiert?**

○ Ja, sehr oft

○ Ja, oft

○ Ja, gelegentlich

○ Ja, selten

○ Nein, nie

## I – Stromverbrauch

**1. Welche der folgenden Informationsquellen haben Sie hierfür genutzt (Mehrfachnennung möglich):**

☐ Zeitung

☐ Fachzeitschrift

☐ Elektronische Medien (Fernsehen, Radio)

☐ Internet

☐ Broschüren

☐ Handwerker

☐ Informationsveranstaltungen

☐ Persönliche Beratung

☐ Sonstiges

# I – Stromverbrauch

## 1. Was trifft auf Ihr Verhalten zu? Bitte kreuzen Sie an, was am ehesten zutrifft.

| | trifft voll und ganz zu | trifft eher zu | teils/teils | trifft eher nicht zu | trifft überhaupt nicht zu | **weiß nicht** |
|---|---|---|---|---|---|---|
| Normalerweise schalte ich das Licht aus, wenn ich einen Raum verlasse. | ○ | ○ | ○ | ○ | ○ | ○ |
| Normalerweise lasse ich meinen Computer ständig laufen, auch wenn ich ihn zwischendurch lange nicht benutze. | ○ | ○ | ○ | ○ | ○ | ○ |
| Wenn möglich, trockne ich meine Wäsche gerne an der Leine und nicht im Trockner. | ○ | ○ | ○ | ○ | ○ | ○ |
| Ich lasse Geräte im Stand-By-Modus, wenn ich sie längere Zeit nicht nutze. | ○ | ○ | ○ | ○ | ○ | ○ |
| Ich achte sehr darauf, dass in meinem Haushalt wann immer möglich Strom eingespart wird. | ○ | ○ | ○ | ○ | ○ | ○ |

## 2. Wir möchten Sie bitten, folgende Aussagen zu bewerten. Bitte kreuzen Sie an, was am ehesten zutrifft.

| | trifft voll und ganz zu | trifft eher zu | teils/teils | trifft eher nicht zu | trifft überhaupt nicht zu | **weiß nicht** |
|---|---|---|---|---|---|---|
| Solange große Unternehmen so viel Strom verbrauchen wie bisher, sehe ich nicht ein, dass ausgerechnet ich Strom sparen soll. | ○ | ○ | ○ | ○ | ○ | ○ |
| Ob ich etwas weniger oder mehr Strom im Monat verbrauche, macht für die Umwelt so gut wie keinen Unterschied. | ○ | ○ | ○ | ○ | ○ | ○ |
| Die meisten Menschen, die mir wichtig sind (z.B. Freunde/Familie, Nachbarn), finden es gut, dass ich sparsam mit Strom umgehe. | ○ | ○ | ○ | ○ | ○ | ○ |
| Es würde mir leicht fallen, meinen Stromverbrauch um 10% zu reduzieren. | ○ | ○ | ○ | ○ | ○ | ○ |
| Wenn ich mehr Informationen über meinen Stromverbrauch hätte, würde ich wahrscheinlich weniger Strom verbrauchen. | ○ | ○ | ○ | ○ | ○ | ○ |

# II – Intelligente Netze

**Nun geht es um Ihre Einschätzung von Intelligenten Netzen (Smart Grid).**
**Zunächst eine Erklärung, wenn Sie diesen Ausdruck noch nicht kennen!**

Erklärung: Der Begriff intelligentes Stromnetz (englisch smart grid) beschreibt ein Stromnetz, das alle Stationen von der Erzeugung über den Transport, die Speicherung und die Verteilung bis hin zum Verbrauch so ausrichtet, dass Angebot und Nachfrage flexibel aufeinander abgestimmt werden. Dazu zählt auch die Steuerung von Haushaltgeräten beim Endverbraucher.

## 1. Haben Sie sich in der Vergangenheit über die Themen „Energiewende“ bzw. „Intelligente Netze“ informiert?

| | Ja, sehr oft | Ja, oft | Ja, gelegentlich | Ja, selten | Nein, nie |
|---|---|---|---|---|---|
| Energiewende | ○ | ○ | ○ | ○ | ○ |
| Intelligente Netze | ○ | ○ | ○ | ○ | ○ |

## 2. Wenn Ja: Welche der folgenden Informationsquellen haben Sie genutzt (Mehrfachnennung möglich)?

| | Energiewende | Intelligente Netze |
|---|---|---|
| Zeitung | ☐ | ☐ |
| Fachzeitschrift | ☐ | ☐ |
| Elektronische Medien (Fernsehen, Radio) | ☐ | ☐ |
| Internet | ☐ | ☐ |
| Broschüren | ☐ | ☐ |
| Handwerker | ☐ | ☐ |
| Informationsveranstaltungen | ☐ | ☐ |
| Persönliche Beratung | ☐ | ☐ |
| Sonstiges | ☐ | ☐ |

## 3. Nun geht es um Ihre Meinungen über Energiewende. Bitte kreuzen Sie in folgender Tabelle an, was Ihre Meinung am ehesten wiedergibt.

| | trifft voll und ganz zu | trifft eher zu | teils/teils | trifft eher nicht zu | trifft überhaupt nicht zu | **weiß nicht** |
|---|---|---|---|---|---|---|
| Die Vor- und Nachteile der Energiewende sind für mich offenkundig. | ○ | ○ | ○ | ○ | ○ | ○ |
| Ich habe keine Ahnung, was mit der Energiewende auf mich zukommt. | ○ | ○ | ○ | ○ | ○ | ○ |
| Ich möchte die Ziele der Energiewende gerne unterstützen. | ○ | ○ | ○ | ○ | ○ | ○ |

### 4. Nun geht es um Ihre Meinungen über Intelligente Netze (Smart Grid).
### Bitte kreuzen Sie in folgender Tabelle an, was Ihre Meinung am ehesten wiedergibt.

| | trifft voll und ganz zu | trifft eher zu | teils/teils | trifft eher nicht zu | trifft überhaupt nicht zu | **weiß nicht** |
|---|---|---|---|---|---|---|
| Die Vor- und Nachteile von Smart Grid sind für mich offenkundig. | ○ | ○ | ○ | ○ | ○ | ○ |
| Smart Grid wird sich in Deutschland nicht durchsetzen. | ○ | ○ | ○ | ○ | ○ | ○ |
| Wenn mein Stromanbieter mir ermöglichen würde, an einem Smart Grid Versuch teilzunehmen, würde ich sehr wahrscheinlich mitmachen. | ○ | ○ | ○ | ○ | ○ | ○ |
| Die meisten Menschen, die mir wichtig sind (z.B. Freunde/Familie, Nachbarn), finden es gut, dass ich dafür bin. | ○ | ○ | ○ | ○ | ○ | ○ |
| Ich bin für die Einführung von Smart Grid, weil es einen Beitrag zur nachhaltigen Gesellschaft leistet. | ○ | ○ | ○ | ○ | ○ | ○ |
| Ich bin gegen die Einführung von Smart Grid, weil die Kosten zu hoch sind. | ○ | ○ | ○ | ○ | ○ | ○ |
| Ich bin gegen die Einführung von Smart Grid, weil ich damit den Stromversorgern erlauben würde, meinen Stromverbrauch zu kontrollieren. | ○ | ○ | ○ | ○ | ○ | ○ |

## II – Intelligente Netze

### 1. Nutzen Sie oder Ihre Familie einen Smart Meter (Gerät zur Rückmeldung über Ihren Stromverbrauch)?

○ Ja

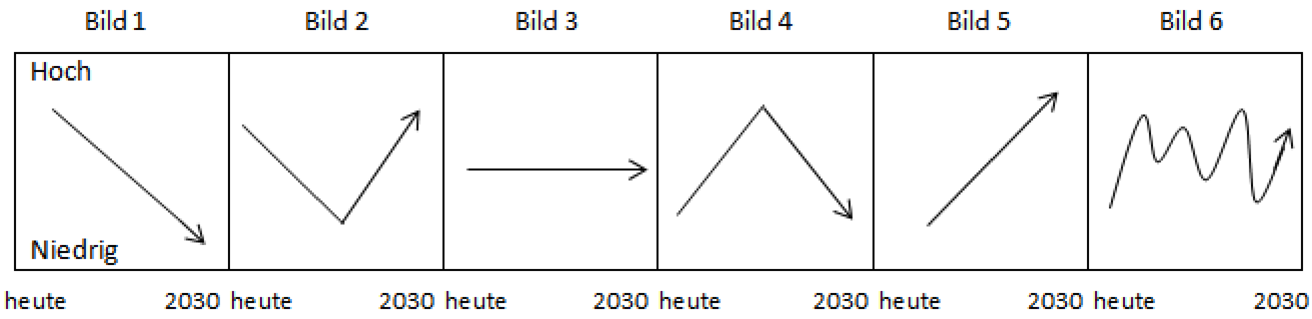
○ Nein, aber die Anschaffung ist geplant.

○ Nein

○ weiß nicht

### 2. Welches Bild zeigt Ihrer Meinung nach die künftige Entwicklung des Strompreises in Deutschland an?

○ Bild 1 ○ Bild 2 ○ Bild 3 ○ Bild 4 ○ Bild 5 ○ Bild 6




**3. Nehmen Sie einmal an, es gäbe keine Energiewende und wir würden weiterhin ausschließlich mit Öl, Gas, Kohle und Kernkraft Strom erzeugen. Welche Strompreisentwicklung würden Sie unter diesen Umständen erwarten?**

○ Bild 1 ○ Bild 2 ○ Bild 3 ○ Bild 4 ○ Bild 5 ○ Bild 6

**4. Was meinen Sie?**
**Wird die Energiewende die Branche, in der Sie selbst oder der Haupteinkommensträger (in) Ihres Haushalts beschäftigt ist, in Zukunft positiv oder negativ beeinflussen?**

○ Sehr negativ

○ Eher negativ

○ weder negative, noch positiv

○ Eher positiv

○ Sehr positiv

○ weiß nicht

**5. In welcher Branche arbeiten Sie bzw. der oder die Haupteinkommensträger(in)?**

○ Bau und Architektur

○ Textil

○ Chemie

○ Metall

○ Papier

○ Automobil

○ Maschinenbau

○ Transport, Verkehr und Logistik

○ Elektronik

○ Informatik

○ Telekommunikation

○ Energieversorgung (allgemein)

○ Kernenergie

○ Erneuerbare Energie

○ Umweltplanung

○ Handwerk

○ Handel

○ Dienstleistung

○ Öffentliche Hand

○ Bund

○ Freie Berufe

○ Andere Branche (bitte angeben)

## II – Intelligente Netze

**1. Wenn kein Wind weht und keine Sonne scheint: Wie soll der Energiebedarf dann gedeckt werden?**
**Tragen Sie in die untenstehende Tabelle bitte eine Zahl von 0-10 ein.**
**Die Ziffer 10 bedeutet, dass Sie diese Option besonders bevorzugen; die Ziffer 0 bedeutet, dass Sie diese Option völlig ablehnen. Die Ziffern 1-9 geben den Grad der Ablehnung bzw. Zustimmung an.**

| | |
|---|---|
| Energieimporte aus anderen Ländern | |
| Fossile Energien (Öl, Gas, Kohle) | |
| Große zentrale Energiespeicher (wie Pumpspeicherkraftwerke) | |
| Kleine dezentrale Energiespeicher (wie hausinterne Batterien) | |
| Stromverbrauch senken, indem in Spitzenzeiten der Strompreis stark angehoben wird | |
| Stromverbrauch senken, indem in Spitzenzeiten besondere Absprachen mit den Kunden getroffen werden, energieintensive Geräte abzuschalten | |
| Stromverbrauch senken, indem in Spitzenzeiten die Abnahmemenge beim Verbraucher auf einen vorher festgelegten Maximalwert gedrosselt wird | |

**2. Welche 3 der obergenannten 7 Optionen würden Sie besonders bevorzugen? Und dann tragen Sie bitte die Zahl 1, 2, oder 3 ein (1 für erste Wahl; 2 für zweite Wahl; 3 für dritte Wahl).**

| | |
|---|---|
| Energieimporte aus anderen Ländern | |
| Fossile Energien (Öl, Gas, Kohle) | |
| Große zentrale Energiespeicher (wie Pumpspeicherkraftwerke) | |
| Kleine dezentrale Energiespeicher (wie hausinterne Batterien) | |
| Stromverbrauch senken, indem in Spitzenzeiten der Strompreis stark angehoben wird | |
| Stromverbrauch senken, indem in Spitzenzeiten besondere Absprachen mit den Kunden getroffen werden, energieintensive Geräte abzuschalten | |
| Stromverbrauch senken, indem in Spitzenzeiten die Abnahmemenge beim Verbraucher auf einen vorher festgelegten Maximalwert gedrosselt wird | |

## 3. Inzwischen gibt es einige Vorschläge wie man die Versorgung mit Strom sicherstellen kann, auch wenn gerade kein Wind weht oder die Sonne nicht scheint. Welche der folgenden Möglichkeiten käme für Sie in Betracht? Bitte kreuzen Sie an, was Ihre Meinung am besten wiedergibt.

| | Käme für mich gar nicht infrage (-2) | Käme für mich eher nicht infrage (-1) | Da bin ich unentschlossen (0) | Käme für mich eventuell infrage (+1) | Käme für mich sehr infrage (+2) | weiß nicht |
|---|---|---|---|---|---|---|
| Ein Stromtarif, bei dem der Anbieter Ihnen eine Anzeige in jedem gewünschten Zimmer installiert, wo sie den momentanen Strompreis ablesen können. Wenn wenig Strom vorhanden ist, geht der Preis steil nach oben; wenn viel da ist, ist der Strom besonders billig. | ○ | ○ | ○ | ○ | ○ | ○ |
| Ein Stromtarif, bei dem der Anbieter Ihnen einen Speicher im Haus installiert, der genug Strom für unverzichtbare Leistungen wie Beleuchtung, Kühlschrank und Gefriertruhe bereitstellt, wenn einmal wenig Strom vorhanden ist. | ○ | ○ | ○ | ○ | ○ | ○ |
| Ein Stromtarif, bei dem der Anbieter für maximal zwei Stunden den Strom abstellen kann, wenn wenig Strom vorhanden ist. Für jede abgestellte Stunde erhalten Sie aber 10% Ihrer Stromrechnung für diesen Monat erlassen. | ○ | ○ | ○ | ○ | ○ | ○ |

## 4. Wie hoch ist Ihr Vertrauen, dass Ihr jetziger Stromanbieter den Datenschutz ernst nimmt und alle Verbrauchsdaten vertraulich behandelt?

- ○ sehr hoch
- ○ hoch
- ○ teils/teils
- ○ gering
- ○ sehr gering
- ○ weiß nicht

## 5. Ich wäre damit einverstanden, dass mein Stromanbieter Daten über meinen Stromverbrauch sammelt, um damit Angebot und Nachfrage besser abstimmen zu können.

- ○ stimme voll und ganz zu
- ○ stimme eher zu
- ○ teils/teils
- ○ lehne eher ab
- ○ lehne voll und ganz ab
- ○ weiß nicht

## 6. Von welchem Anbieter beziehen Sie derzeit Ihren Strom?

- weiß nicht
- Stadtwerke
- E wie einfach
- EnBW
- E.ON
- Vattenfall
- eprimo
- FlexStrom
- Lichtblick
- Yello
- Andere (bitte angeben)

## 7. Beziehen Sie von Ihrem Anbieter Ökostrom (grünen Strom)?

- Ja
- Zum Teil
- Nein
- weiß nicht

# III – Energiesparen

## 1. Ist Ihnen dieses Schaubild an elektrischen Geräten schon aufgefallen?

- Ja, sehr oft
- Ja, oft
- Ja, gelegentlich
- Ja, selten
- Nein, nie

## 2. Welchen Typ von Fernseher (TV) haben Sie (Mehrfachnennung möglich)?

- ☐ Plasma-TV
- ☐ LCD / LED-TV
- ☐ PC mit TV-Karte
- ☐ Röhren TV
- ☐ Kein TV
- ☐ weiß nicht

## 3. Womit beleuchten Sie Ihre Räume überwiegend (maximal 2 ankreuzen)?

- ☐ Glühbirnen
- ☐ Halogenlampen
- ☐ Energiesparlampen
- ☐ LED-Lampen
- ☐ Mischung

## 4. Bitte schätzen Sie ein: Wie häufig (x mal pro Woche) finden folgende Tätigkeiten in Ihrem Haushalt statt? Wenn Sie Backofen z. B. 1 mal pro zwei Wochen benutzen, können Sie 0,5 eintragen. Wenn Sie eine Frage nicht wissen, können Sie diese Frage überspringen.

| | |
|---|---|
| Waschgänge mit Waschmaschine | |
| Trockenvorgänge mit Trockner | |
| Spülgänge mit der Geschirrspülmaschine | |
| Kochen mit dem Elektroherd | |
| Benutzung der Backofens | |

### 5. Was trifft auf Ihr eigenes Verhalten zu? Bitte kreuzen Sie an, was am ehesten zutrifft.

| | trifft voll und ganz zu | trifft eher zu | teils/teils | trifft eher nicht zu | trifft überhaupt nicht zu | **weiß nicht** | **habe ich nicht** |
|---|---|---|---|---|---|---|---|
| Wenn ich die Waschmaschine benutze, wähle ich normalerweise das Eco/Energiesparprogramm. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Wenn ich die Geschirrspülmaschine benutze, wähle ich normalerweise das Eco/Energiesparprogramm. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Wenn ich den Computer benutze, aktiviere ich normalerweise den Energiesparmodus. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Ich schalte Geräte wie Fernseher und DVD-player vollkommen aus, wenn ich diese lange Zeit nicht benutze. | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

## III – Energiesparen

### 1. Wir möchten Sie bitten, folgende Aussagen zu bewerten. Bitte kreuzen Sie an, was am ehesten zutrifft.

| | trifft voll und ganz zu | trifft eher zu | teils/teils | trifft eher nicht zu | trifft überhaupt nicht zu | **weiß nicht** |
|---|---|---|---|---|---|---|
| Beim Kauf eines Elektrogerätes ist für mich der Stromverbrauch sehr wichtig. | ○ | ○ | ○ | ○ | ○ | ○ |
| Der Preis eines Elektrogerätes ist mir wichtiger als sein Stromverbrauch. | ○ | ○ | ○ | ○ | ○ | ○ |
| Bei günstiger Finanzierungsmöglichkeit (z.B. Ratenzahlung) greife ich auch gerne zu energiesparenden Haushaltsgeräten. | ○ | ○ | ○ | ○ | ○ | ○ |
| Ich würde gerne mehr über die Vorteile von energiesparenden Geräten erfahren, bevor ich dafür mehr Geld ausgebe. | ○ | ○ | ○ | ○ | ○ | ○ |
| Ich will in Zukunft mehr energiesparende Elektrogeräte anschaffen, weil ich langfristig Geld sparen kann. | ○ | ○ | ○ | ○ | ○ | ○ |
| Ich will in Zukunft mehr energiesparende Elektrogeräte anschaffen, weil der Umweltschutz mir sehr wichtig ist. | ○ | ○ | ○ | ○ | ○ | ○ |

## IV – Erneuerbare Energien und Stromerzeugung

**1. Wenn ein neuer Windpark in Ihrem Wohnumfeld gebaut werden sollte (ca. 10km weit von Ihrer Wohnung), würden Sie das:**

- stark ablehnen
- eher ablehnen
- teils/teils
- eher zustimmen
- stark zustimmen
- wäre Ihnen egal

**2. Wenn eine große Solaranlage in Ihrem Wohnumfeld gebaut werden sollte (ca. 10km weit von Ihrer Wohnung), würden Sie das:**

- stark ablehnen
- eher ablehnen
- teils/teils
- eher zustimmen
- stark zustimmen
- wäre Ihnen egal

**3. Haben Sie sich schon über die Installation einer Anlage für die erneuerbare Energie in Ihrem Haushalt informiert?**

- Ja, sehr oft
- Ja, oft
- Ja, gelegentlich
- Ja, selten
- Nein, nie

## IV – Erneuerbare Energien und Stromerzeugung

### 1. Welche der folgenden Informationsquellen haben Sie hierfür genutzt (Mehrfachnennung möglich):

- ☐ Zeitung
- ☐ Fachzeitschrift
- ☐ Elektronische Medien (Fernsehen, Radio)
- ☐ Internet
- ☐ Broschüren
- ☐ Handwerker
- ☐ Informationsveranstaltungen
- ☐ Persönliche Beratung
- ☐ Sonstiges

## IV – Erneuerbare Energien und Stromerzeugung

### 1. Nun geht es um Ihre Erfahrung mit Windkraftanlagen. Bitte kreuzen Sie an, was am ehesten zutrifft.

| | Ja | Nein | **weiß nicht** |
|---|---|---|---|
| Windkraftanlagen sind in der Nähe meines Wohnortes installiert. | ○ | ○ | ○ |
| Ich kenne Personen, die an dem Bau und Betrieb von Windkraftanlagen beteiligt sind. | ○ | ○ | ○ |
| Ich/Meine Familie habe/hat selbst in Windkraftanlagen investiert. | ○ | ○ | ○ |

### 2. Nun geht es um Ihre Erfahrung mit Photovoltaikanlagen (Solarzellen für Stromerzeugung). Bitte kreuzen Sie an, was am ehesten zutrifft.

| | Ja | Nein | **weiß nicht** |
|---|---|---|---|
| Photovoltaikanlagen gibt es an meinem Wohnort. | ○ | ○ | ○ |
| Ich kenne Personen, die Photovoltaikanlagen auf ihrem Dach installiert haben. | ○ | ○ | ○ |
| Ich/Meine Familie habe/hat selbst in Solarzellen investiert. | ○ | ○ | ○ |

## IV – Erneuerbare Energien und Stromerzeugung

### 1. Sind Sie/Ihre Familie Eigentümer oder Mieter Ihrer Wohnung/ Ihres Hauses?

- ○ Eigentümer
- ○ Mieter

## IV – Erneuerbare Energien und Stromerzeugung

**Sofern Sie Mieter sind: Bitte beantworten Sie die folgenden Fragen so, als ob Sie selbst der Eigentümer wären.**

## IV – Erneuerbare Energien und Stromerzeugung

### 1. Wenn es möglich wäre, könnten Sie sich vorstellen, eine Photovoltaikanlage auf dem Dach Ihres Hauses installieren zu lassen?

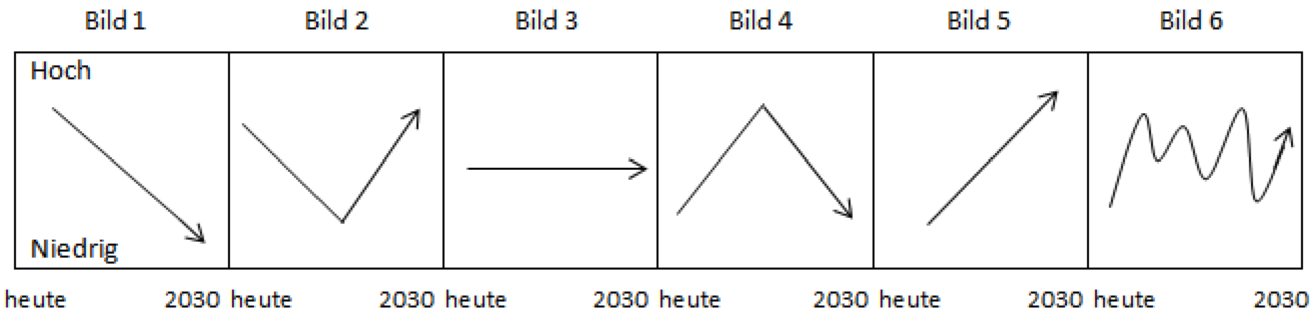
- ○ Ja
- ○ Vieleicht
- ○ Nein
- ○ weiß nicht

### 2. Bitte kreuzen Sie an, wie Sie zur Stromerzeugung mit Photovoltaikanlagen für den eigenen Haushalt stehen. Halte ich für:

| | trifft voll und ganz zu | trifft eher zu | teils/teils | trifft eher nicht zu | trifft überhaupt nicht zu | **weiß nicht** |
|---|---|---|---|---|---|---|
| zu teuer | ○ | ○ | ○ | ○ | ○ | ○ |
| umweltschädlich | ○ | ○ | ○ | ○ | ○ | ○ |
| hässlich | ○ | ○ | ○ | ○ | ○ | ○ |
| modern | ○ | ○ | ○ | ○ | ○ | ○ |
| zuverlässig | ○ | ○ | ○ | ○ | ○ | ○ |
| wartungsintensiv | ○ | ○ | ○ | ○ | ○ | ○ |
| macht unabhängig vom Stromversorger | ○ | ○ | ○ | ○ | ○ | ○ |
| lohnenswerte Investition | ○ | ○ | ○ | ○ | ○ | ○ |

### 3. Welches Bild zeichnet Ihrer Meinung nach die künftige Preisentwicklung von Photovoltaikanlagen in Deutschland am ehesten ab?

○ Bild 1 ○ Bild 2 ○ Bild 3 ○ Bild 4 ○ Bild 5 ○ Bild 6



**4. Was meinen Sie? Wie viele Jahre dauert es, bis sich eine Photovoltaikanlage auf Ihrem Hausdach rentieren würde?**

- weniger als 5 Jahre
- 5-10Jahre
- 11-15Jahre
- 16-20Jahre
- 21Jahre und mehr
- rentiert sich nie

**5. Bitte kreuzen Sie in folgender Tabelle an, was Ihre Meinung über Photovoltaikanlagen am ehesten wiedergibt.**

| | trifft voll und ganz zu | trifft eher zu | teils/teils | trifft eher nicht zu | trifft überhaupt nicht zu | **weiß nicht** |
|---|---|---|---|---|---|---|
| Ich glaube, dass diese Technologie in Zukunft überall in Deutschland verbreitet sein wird. | ○ | ○ | ○ | ○ | ○ | ○ |
| Die meisten Menschen, die mir wichtig sind (z.B. Freunde/Familie, Nachbarn), finden es gut, wenn ich eine Photovoltaikanlage installieren würde. | ○ | ○ | ○ | ○ | ○ | ○ |
| Ich kann Freuden und Bekannten ruhigen Gewissens empfehlen, eine Photovoltaikanlage auf dem Dach zu installieren. | ○ | ○ | ○ | ○ | ○ | ○ |

## V - Zu Ihrer Person

**1. In welchem Jahr sind Sie geboren?**

**2. Sie sind:**

- männlich
- weiblich

**3. Welches ist Ihr höchster Bildungsabschluss?**

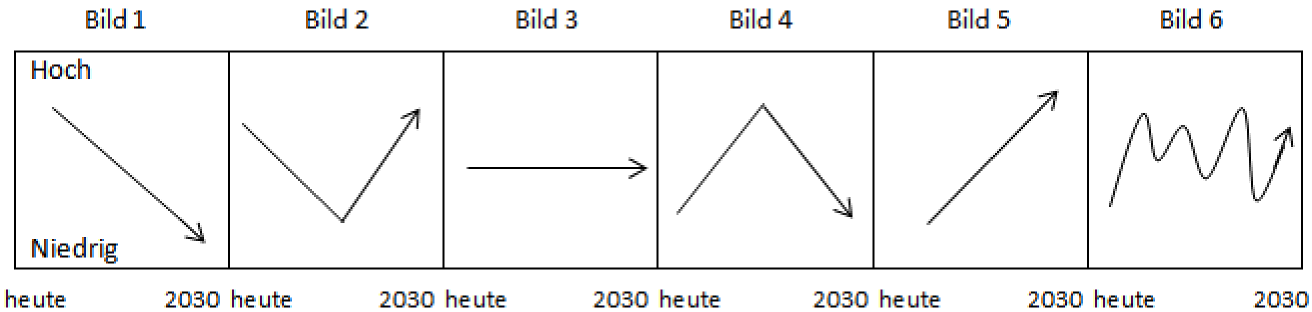
- Kein Abschluss
- Noch Schüler
- Volks- oder Hauptschulabschluss
- Mittlere Reife / Realschulabschluss / Polytechnische Oberschule
- Fachhochschulreife
- Allgemeine Hochschulreife/Abitur
- Abgeschlossenes Hochschulstudium
- Promotion
- Ausländischer Abschluss ohne bekanntes deutsches Äquivalent

**4. Bitte schätzen Sie Ihr monatliches Haushaltsnettoeinkommen, und kreuzen Sie bitte an.**

- ○ unter 900 €
- ○ 901 bis unter 1300 €
- ○ 1301 bis unter 1500 €
- ○ 1501 bis unter 2000€
- ○ 2001 bis unter 2600€
- ○ 2601 bis unter 4000€
- ○ 4001 bis unter 5000€
- ○ 5001 € und mehr

**5. Welches Bild zeigt Ihrer Meinung nach die Entwicklung Ihres Einkommens in Zukunft?**

○ Bild 1 ○ Bild 2 ○ Bild 3 ○ Bild 4 ○ Bild 5 ○ Bild 6




**6. Bitte tragen Sie hier noch die ersten 3 Stellen Ihrer Postleizahl ein, damit wir Ihren Haushalt grob einem Gebiet zuordnen können.**

PLZ:

## Geschafft! Vielen herzlichen Dank für Ihre Teilnahme!

Wenn Sie an den Ergebnissen interessiert sind, können Sie eine Email schreiben an: Frau Li, *Huijie.li@sowi.uni-stuttgart.de*