

TURN IT ON! – USER ACCEPTANCE OF DIRECT LOAD CONTROL AND LOAD SHIFTING OF HOME APPLIANCES

Research paper

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Abstract

In 2030 at latest, half of the power production in Germany has to consist of renewable energy. The problem is not to produce enough renewable energy but to provide it when needed and to control it in such a way that the electricity system does not collapse. Direct load control (DLC) is seen as a great opportunity to solve the big problem of the energy turnaround. Therefore, this paper examines drivers and barriers for the acceptance towards load shifting of home appliances. Particularly the role of trust in the energy provider is under investigation. For this, we conducted a survey among 653 end consumers. Results show that on the one hand the ecological impact, the increased comfort, and the financial benefits influence the acceptance of DLC. On the other hand, the loss of control, the technical safety, and not well protected usage profiles decrease the acceptance. While trust in the provider does not impact the attitude towards DLC directly, it plays an important role for the perception of advantages and disadvantages.

Keywords: Demand side management, direct load control, load shifting, energy turnaround, user acceptance, trust.

1 Introduction

In 1990, Germany regulated the energy market for renewable energy sources and guaranteed a payment that for example enabled wind turbines to produce energy economically. Ten years later, the so-called EEG (“Gesetz für den Vorrang erneuerbarer Energien“) was enacted and replaced the former law of 1990. The EEG of 2000 differentiated the payments for each renewable energy source and defined a limit for solar energy. If more than 350MW were produced, the support for solar energy would be stopped. Because this limit was reached in 2003 which would have implied a collapse in the photovoltaic market, a new EEG was enacted for 2004. In the meantime, the EU also published several directives concerning renewable energy (2001/77/EC, 2003/30/EC, and later on 2009/28/EC). Germany reacted with a revision of the EEG in 2009. Then, in 2011, the Fukushima accident took place and changed pace rapidly. Germany again revised its EEG in 2012. Now, it comprises a schedule towards the year 2050. In 2030 at latest, half of the power production in Germany has to consist of renewable energy. Taking into account that in 2011 after 20 years of encouraging renewable energy only 20.4% of the power consumption in Germany was covered by renewable energy sources (AG Energiebilanzen e.V., 2014), this goal does not seem to be reached easily. The problem is not to produce enough renewable energy but to provide it when needed and to control it such that the electricity system does not collapse. While conventional energy sources like coal, gas, or nuclear energy can be controlled easily with respect to special requirements concerning power up and down times, the production of

renewable energy heavily depends on natural factors like the weather (sun, wind, water). On a cloudy, windless day, photovoltaic systems and wind turbines can hardly be used while on windy and very sunny days, often more renewable energy is produced than it is needed. However, Germany managed to raise the share of renewable energy to nearly 25% in 2013 (AG Energiebilanzen e.V., 2014) and therefore already exceeds the target value of 18% of EU directive 2009/28/EC for the year 2020. This current value is more than double of the share that is estimated for the US for the year 2020 (Cappers et al., 2012)

But the higher the share of renewable energy sources is, the more difficult it is to plan and to control the energy production in total (Bartels et al., 2006; Finn et al., 2013; Paulus and Borggreffe, 2011) such that there is neither an overproduction nor an underproduction. Therefore, in periods of underproduction conventional energy sources have to be used. In a period of overproduction it may happen that power plants for renewable energy have to be shut down for a stable energy supply because the storage capacity for energy is not sufficient (Schill, 2014). Then, all renewable energy that cannot be stored during this period is completely lost while in other periods conventional energy has to be used.

In general, there exist two approaches to avoid this waste of power: The first approach deals with the possibilities to accumulate the energy so that it can be used in periods of power shortage. But studies have shown that the current storage capacity is not sufficient (Schill, 2014). The second approach is called Demand Side Management (DSM), Demand Response (DR), or Demand Side Integration (DSI). Its general idea is to influence the demand side such that the energy demand is adapted to the energy production. DSM comprises all activities that concern the energy management at the demand side, e.g. saving energy by using power saving utilities or monitoring the energy consumption (Paulus and Borggreffe, 2011). The term DR is used when measures of the supply side are used that aim to induce special responses of the demand side, e.g. different pricing strategies (Cappers et al., 2012). DSI is the superordinate concept and includes both strategies (Chuang and Gellings, 2008).

This paper deals with the second approach of DSI for households. The technological progress and the triumphal procession of the internet make it possible to communicate with any kind of technical equipment in households like heating, coffee machines, refrigerators etc. This makes suppliers of energy as well as research or politics dream of remote controlling energy consuming equipment in households in order to arrange the power consumption such that it is more steady and constant as well as to balance the oscillation of renewable energy production. In many recent publications, this concept of direct load control (DLC) is seen as a great opportunity to solve the big problem of the energy turnaround, the problem of energy production in times of low power demand and vice versa (Paetz et al., 2012; Zhou et al., 2008). Indeed, DLC is promising. If it is possible to shift the power consumption from periods with low renewable energy production to periods with high renewable energy production, the more renewable energy can be used and the less power is wasted or has to be stored. But obviously it is not possible to shift the working time of each electric device (Paetz et al., 2012). Usually, only a few home appliances are suitable for load shifting (LS) like heating systems, refrigerators, washing machines, or dishwashers. For other devices like televisions or coffee machines, consumers would not accept a time shifting (Paetz et al., 2012). But despite some promising pre-tests (Hargreaves et al., 2010; Mert et al., 2008), it is questionable if and to which degree consumers would accept that energy suppliers control their home appliances. Reasons to disapprove DLC and LS may not only be a possible loss of convenience (Mert et al., 2008; Paetz et al., 2012) but also a lack of trust towards the energy supplier (Balta-Ozkan et al., 2013; Chen et al., 2017; Hargreaves et al., 2010; Park et al., 2014). If the supplier who is paid for the energy controls the appliances that consume the energy, one could suspect that the supplier follows his own agenda of maximising his profit instead of minimising the costs of his customers (Annala et al., 2012; Balta-Ozkan et al., 2013; Goulden et al., 2014). Therefore, this paper focuses on the user acceptance of the DSI measure load shifting. For this, we have a look at the benefits users expect and the disadvantages they fear to suffer from and prohibit them to participate in LS programs. In particular, we focus on the role of trust towards the energy supplier. If users mistrust their energy supplier and fear that their participation in LS programs is misused, it can

hardly be imagined that they would provide home appliances for LS. Hence, the following research questions should be answered:

RQ1: What drives consumers to accept or refuse load shifting of home appliances?

RQ2: Which role does trust towards the energy supplier play for participating in load shifting?

For this, we conducted a survey among 653 consumers. The remainder of this paper is organised as follows. In the next section, we review the related literature in the field of LS and demonstrate the contribution of this paper. The third section develops the research model that is analysed in section 4. The paper closes with a discussion of the result.

2 Literature Review

DSI measures for industry and craft like LS are used since many years (Chu et al., 1993; Sanghvi, 1989) on an individual basis (Weers and Shamsedin, 1987). The potential depends on the branch so that usually only case studies are presented (e.g. Ashok and Banerjee, 2000; Middelberg et al., 2009) or special branches are analysed (Paulus and Borggreffe, 2011). During the past years, many studies and field tests have been done concerning private households. Beside the analysis of technical details and requirements (e.g. Deese et al., 2013; Moneta et al., 2007; Weers and Shamsedin, 1987), the consumer perception of DSI is getting more and more into the focus of investigation. Some papers tried to find out who is receptive for energy saving (Herter, 2007; Mills and Schleich, 2012) and special tariffs (Ericson, 2011), which tariffs consumers prefer (Dütschke and Paetz, 2013; Dütschke et al., 2012), if contracts should provide an opt-in or opt-out option (Toft et al., 2014), how consumers react when they are informed about their energy consumption (Hargreaves et al., 2010), and how much energy is saved then (Schleich et al., 2011).

Smart meters that offer a bidirectional communication are a prerequisite for DLC and LS (Stragier et al., 2010). While in Italy for example most households are already equipped with smart meters (Torriti et al., 2010), the diffusion in Germany is still low (Bundesnetzagentur and Bundeskartellamt, 2017). Therefore, many authors investigated the acceptance of smart meters by consumers using different approaches. Krishnamurti et al. (2012) analysed the expectations towards smart meters and found that many consumers have erroneous beliefs regarding their purpose and functionality as well as they overestimate their benefits. Therefore, most interviewees have been very open-minded about smart meters although they also perceived several risks. Gerpott and Paukert (2013) had a look at the willingness of consumers to pay (WTP) for smart meters. They found that the trust in the provider and the intention of users to change their energy consumption behaviour are the best predictors for WTP. However, they could only explain 28% of the variance so that many influencing factors remain in the dark.

Chou and Yutami (2014), Chen et al. (2017), Kranz et al. (2010), Kranz and Picot (2011 and 2012), Park et al. (2014), Wunderlich et al. (2012a, 2012b, and 2013) analysed the acceptance of consumers in different countries concerning smart meters. Although several studies mentioned the enabling role of smart meters for LS, none of them considered LS, its advantages, and disadvantages in the questionnaires. Hence, interviewees were asked about their general attitude towards smart meters and influencing factors like expected usefulness, ease of use, behavioural control etc. Other factors under investigation were for example program features and complexity (Chou and Yutami, 2014), trust, energy saving habits, and political disposition (Chen et al., 2017), price consciousness and environmental concerns (Kranz and Picot, 2011 and 2012), subjective control (Kranz et al., 2010), perceived locus of control (Wunderlich et al., 2012a, 2012b, 2013), or perceived reliability of the provider (Park et al. 2014). But one of the most important features for matching energy demand and supply, namely the possibility for utilities to switch off and on devices and shift the operating time to other periods was not mentioned to interviewees within the surveys. Therefore, although different factors like privacy concerns, trust towards the energy provider, or costs have been under investigation, their impact on the acceptance of LS is still unclear.

In contrast, Stragier et al. (2010), Paetz et al. (2012), Balta-Ozkan et al. (2013), Toft et al. (2014), and Ahn et al. (2016) focused on smart devices and as such on their possibility of self-control. Stragier et al. (2010) analysed the perception of consumers towards smart devices and the changing energy management in the daily life. They found that the general attitude of consumers mediates usefulness and usability and has a high impact on the intention to use smart devices. Balta-Ozkan et al. (2013) investigated the barriers for adopting smart meters. Their results show that in general users like the idea of devices that save energy for them. But they have concerns about the costs and the privacy of personal data. Paetz et al. (2012) introduced interviewees to a smart home prototype so that they were aware of the functioning of smart devices. In general, participants had a positive attitude towards the smart home. The best motivators to use smart devices are cost savings but consumers have an ambivalent view on the cost saving potentials as they mistrust the utility. Toft et al. (2014) as well as Ahn et al. (2016) focused on smart heating and cooling systems. Toft et al. (2014) found that besides usefulness feelings of moral obligations towards the environment have a positive impact on the acceptance of smart heating. But Ahn et al. (2016) could not confirm an impact of environmental concerns on the intention to use such smart thermostats.

Although these papers investigated smart devices that act self-controlled or can be controlled by energy providers, the focus was more on the devices and how they are perceived by consumers. In contrast to these papers, Annala et al. (2012) as well as Mert et al. (2008) focused on DLC itself. While Annala et al. (2012) had a more general look at the attitude of consumers towards DLC, Mert et al. (2008) also investigated different home appliances and to what extent these would be accepted to be shifted. Annala et al. (2012) observed a general wish among the respondents of retaining their own control and a concern about data security. Mert et al. (2008) found a high acceptance rate of usually more than 85% for DLC. However, respondents would only partly accept a change of their usage behaviour. On average, they would accept LS of three hours. Interestingly, many interviewees had no concerns about the collected data but about technical failures and a loss of comfort.

Unfortunately, neither Annala et al. (2012) nor Mert et al. (2008) analysed causal relationships between benefits and concerns on the one side and the acceptance of respondents to participate in DLC programs on the other side. Therefore, this paper is the first that analyses factors influencing the acceptance and intention of consumers to participate in DLC programs. In particular, we focus not only on benefits but also on potential disadvantages users may fear to suffer from. Additionally, we have a look at the role of trust towards of the energy supplier who controls smart devices instead of the consumer and therefore receives much information about the habits of his customers. Hence, the perception of the energy supplier may play an important role for the acceptance of consumers.

3 Research Model

Acceptance is the willingness to positively approve someone or something, usually some kind of innovation like a new product or a new service. We can distinguish three different kinds of acceptance (Kjellen and Sklet, 1995). The first kind is the positive attitude towards an innovation. That means a person is mentally prepared and ready for the innovation. The second kind of acceptance is the intention to use the innovation while the third kind of acceptance deals with the usage of the innovation itself. The first two kinds of acceptance can already exist before a person has ever used the innovation. But only while or after usage, a permanent acceptance can appear (Wirtz et al. 2012).

Davis (1986 and 1989) incorporated these different kinds of acceptance into his well-known Technology Acceptance Model (TAM) that is based on Ajzen's and Fishbein's Theory of Reasoned Action (Ajzen and Fishbein, 1980; Fishbein and Ajzen, 1975). Although TAM is sometimes criticised for its simplicity (Lee et al., 2003), it is often used to measure the acceptance of technical innovation (Chau and Hu, 2002; Ma and Liu, 2004) because it possesses a very high explanatory power (Mathieson, 1991; Venkatesh and Davis, 2000; Gentry and Calantone, 2002). The TAM core states that the attitude towards an innovation (1st kind) influences the behavioural intention to use it (2nd kind) that again has an impact on the actual use (3rd kind). Because DSI and in particular LS of home appliances is still in

its infancy, most people have not heard about it or got in contact with such measures. Therefore, investigating the actual (non-existing) usage would bring no result. In addition, the intention to use an innovation has been proven many times to be a very good predictor of its usage (Armitage and Conner, 2001; Venkatesh et al., 2003; Vijayasarathy, 2004). Therefore, we resign to measure the actual use and hypothesise:

H1: A positive attitude towards DSI positively influences the intention to participate in DLC.

The attitude towards an innovation is determined by its characteristics and how users perceive and assess these characteristics (Davis, 1986 and 1989). TAM postulates that the usability (ease of use) of an innovation influences the way how users perceive its usefulness. Usability and usefulness in turn both have an impact on the users' attitude towards the innovation (Davis, 1986 and 1989; Venkatesh and Davis, 2000). Several authors could confirm the importance of the usability of smart meters for the acceptance (Toft et al., 2014; Park et al., 2014; Wunderlich et al., 2012a and 2012b). But DLC is currently not available and therefore its usability is hard to assess for consumers. Because of that, we resign to measure the ease of use as its impact is already known and can be seen as prerequisite for any technical innovation. However, even if consumers have no experience with DLC, its usefulness can be judged on the basis of expected advantages and disadvantages. Various studies have already investigated benefits that consumers expect from DLC. Among all expected advantages, consumers name financial benefits (item PA3) in the first place (Annala et al., 2012; Hargreaves et al., 2010; Mert et al., 2008; Paetz et al., 2012). This is usually followed by ecological reasons (PA4) (Hargreaves et al., 2010; Kranz and Picot, 2011; Mert et al., 2008; Toft et al., 2014; Paetz et al., 2012). Other expected advantages of DLC are to do domestic work quicker (PA1) (Balta-Ozkan et al., 2013) and to have more convenience (PA2) (Balta-Ozkan et al., 2013; Mert et al., 2008). Although not initially postulated, Davis (1986) found a relation between perceived usefulness and the intention to use an innovation. Therefore we hypothesise concerning the perceived advantages:

H2a: The perceived advantages positively influence the attitude towards DLC.

H2b: The perceived advantages positively influence the intention to use DLC.

In contrast to other papers, we do not build separate constructs for each benefit but use them as measures for the now formative construct of perceived advantages. The main advantage is that respondents are not asked several times for the same aspect so that the resulting questionnaire can be kept short. The disadvantages are modelled in the same way. While TAM and its successor models focus on a system's benefits and the environmental conditions for its use (Davis, 1986 and 1989; Venkatesh and Davis, 2000; Venkatesh et al., 2003), extensions have proven that also disadvantages and perceived risks have an impact on attitude and intention to use an innovation (Chen et al., 2017; Park et al., 2014). Hence, we do not only measure the perceived usefulness of DLC in terms of its advantages but also the disadvantages in terms of potential threats and personal confinements. To a certain degree, users hand the control over their home appliances over to the energy supplier. This loss of control (item PD5) is reported to be critical to users (Annala et al., 2012; Mert et al., 2008) as they fear that they cannot plan their daily routines exactly (PD6) (Goulden et al., 2014; Paetz et al., 2012). In addition, consumers scrutinise the general functionality and safety of appliances being remotely controlled by utilities (PD4). They fear for example that goods are spoiled in the refrigerator and that these appliances are exposed to higher risks of fire or water damage (Mert et al., 2008). But the main risk of DLC and LS is said to be the privacy risk (Annala et al., 2012; Balta-Ozkan et al., 2013). Due to the remote control of appliances, usage data is collected that can and will be used to derive user profiles, in particular when appliances should learn the behaviour of users. These profiles can be threatened by unauthorised access (PD2) (Annala et al., 2012), used for other purposes (PD1) (Annala et al., 2012; Chen et al., 2017), or can make the routine of the day transparent to others (PD3) (Annala et al., 2012; Balta-Ozkan et al., 2013; Goulden et al., 2014; Paetz et al., 2012). In addition, the smart meter can be hacked so that there is the risk that home appliances are manipulated by unauthorised third parties (PD7) (Krishnamurti et al., 2012). All these factors may influence the attitude of users towards LS. As a result, we hypothesise:

H3a: The perceived disadvantages negatively influence the attitude towards DLC.

H3b: The perceived disadvantages negatively influence the intention to use DLC.

While TAM was developed to analyse the usage behaviour of people, it mainly focuses on system characteristics and their perception by users. But usage behaviour also depends on users themselves and their personal and business environment. Therefore, further developments of TAM were expanded by these factors (Venkatesh and Davis, 2000; Venkatesh et al., 2003). In the context of DLC, factors like job relevance cannot be applied and due to DLC's early stage, performance expectancy as well as output quality must be assumed as given. However, the social influence might play an important role (Kranz and Picot, 2011). The more people of a user's social environment accept an innovation, the more likely this person will usually do so, too (Venkatesh et al., 2003). This phenomenon is usually called subjective norm and depicts the social pressure that people from the personal environment exert knowingly or unconsciously on the user. Therefore, we also employ the subjective norm of the further developments of TAM that measures how much the environment influences a person to use the discussed innovation (Venkatesh and Davis, 2000; Venkatesh et al., 2003). Besides its influence on the intention to use an innovation (Venkatesh and Davis, 2000; Venkatesh et al., 2003), the subjective norm is also found to influence the perceived usefulness (Venkatesh and Davis, 2000; Chou and Yutami, 2014), respectively the advantages, and therefore the perceived disadvantages. Accordingly, we hypothesise:

H4a: The subjective norm positively influences the perceived advantages of DLC.

H4b: The subjective norm negatively influences the perceived disadvantages of DLC.

H5: The subjective norm positively influences the intention to use DLC.

Trust is a multidimensional concept (Mayer et al., 1995; Rousseau et al., 1998, McKnight et al., 2002) and an important antecedent for interactions of people (Gefen et al., 2003; Reichheld and Scheffer, 2000). Menon et al. (1999) regard trust as the belief of the trusting person in attributes of the trustee while Fung and Lee (1999) understand trust as the trustor's willingness to believe the trustee. In other words, trust is "the willingness of a party to be vulnerable to the action of another party [...] irrespective of the ability to monitor or control the other party" (Mayer et al., 1995). Thus, trust exhibits two facets: The involved parties and the control mechanisms (Tan and Thoen, 2000). In general, two parties are involved: The trustor and the trustee (Tan and Thoen, 2000; Chopra and Wallace, 2002; Krasnova et al., 2010). In our case, the trustor is the user who participates in DLC and the trustee is the energy provider. The user enables the energy provider to control the home appliances. Then, trust in the other party means that the user believes in the benevolence of the provider (McKnight et al., 2002). He trusts the energy provider to act in the agreed way. That means the provider turns on and off the devices when it is needed to balance energy supply and demand and does not abuse his control over the devices such that they are turned on when energy costs are just high (Annala et al., 2012; Baltazkan et al., 2013; Goulden et al., 2014; Mert et al., 2008; Paetz et al., 2012). Without trust towards the energy provider, it is therefore doubtful if consumers would participate in DLC (Yang et al., 2017). Therefore we hypothesise:

H6a: Trust in the energy provider positively influences the attitude towards DLC.

In addition, trust is proven to influence the perceived risks (Krasnova et al., 2010), in our terms the perceived disadvantages, and the perceived usefulness (Chen et al., 2017; Park et al., 2014), in our terms the perceived advantages. The control mechanisms are scarce in the case of DLC. The only possibility for users is to check the billing if it is unnaturally high. Only if additional tools are provided like overviews of the energy demand and supply, real-time energy costs etc., a better control can be established. Therefore, we resign to have a look at the control mechanisms and hypothesise:

H6b: Trust in the energy provider positively influences the perceived advantages of DLC.

H6c: Trust in the energy provider negatively influences the perceived disadvantages of DLC.

The resulting research model is depicted in Figure 1.

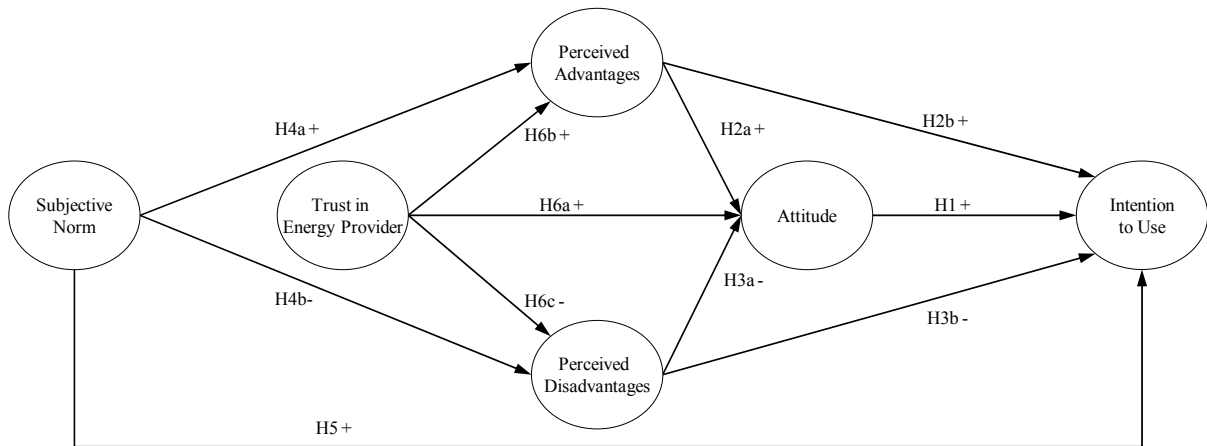


Figure 1. Research Model

4 Analysis

4.1 Data Collection and Analysis Techniques

DLC and LS offer promising opportunities to manage the energy turnaround but due to the disadvantages and concerns discussed in section 3, the willingness of end consumers to participate in such programs is questionable. To assess that willingness for participation in DLC, we conducted an online survey consisting of 24 questions in August 2017 to analyse the structural equation model developed in section 3 and five demographic questions. In total, 653 consumers participated in the survey. Considering the recommendation of Hair et al. (2014), 303 observations with more than 15% missing values had to be eliminated resulting in a total of 350 observations which is beyond the recommended sample size of Chin (1998b) for receiving stable results of the model estimation.

The remaining sample can be described as follows (due to missing values, shares do not necessarily sum up to 100%): The share of male (female) respondents is 66.57% (27.43%). 34.86% of the respondents are between 20 and 29 years old, 30.00% between 30 and 39, 12.57% between 40 and 49, and 15.71% are older. Concerning the level of education, 63.43% are at least graduated. 72.57% of the interviewees are in regular work while only 16.57% are students. The monthly income is quite uniformly distributed in the range of 0€ to 6000€.

Due to the fact that our theoretically developed structural equation model (SEM) consists of reflective as well as formative constructs, we used the software SmartPLS 2.0 (Ringle et al., 2005) for the analysis of the collected data and our SEM. SmartPLS is based on the partial least squares algorithm (PLS). In contrast to covariance-based software as LISREL it is suitable to evaluate reflective as well as formative constructs (Gefen, 2000; Weiber and Mühlhaus, 2014). Furthermore PLS does not restrict the sample size and does not pretend any distributional assumption (Chin et al., 2003;; Cassel et al., 1999). For the analysis of our model with SmartPLS, we follow the guideline of Hair et al. (2014) among others (Henseler et al., 2009; Haenlein and Kaplan, 2004; Huber et al., 2007). In addition to the PLS algorithm a Bootstrapping is used for the determination of the significance of weights, loadings and path coefficients, with case wise replacement, 5000 samples and 350 cases (Hair et al., 2011; Hair et al., 2014; Sarstedt et al., 2014). For testing the model on multicollinearity SPSS is used to conduct a regression analysis.

4.2 Measurement Model

Two kinds of measurement models can be distinguished (Jarvis et al., 2003): reflective and formative measurement models. Concerning reflective measurement models, indicators of a reflective construct are characterisations of the construct and as such influenced by it. In contrast, formative constructs are built by their indicators so that a change in one indicator changes the construct and not vice versa (Bollen and Lennox, 1991; Jarvis et al., 2003). Therefore, both kinds have to be evaluated differently.

For reflective constructs, the indicator reliability, the convergence criterion, the discriminant validity, and the predictive validity have to be considered (Chin, 1998b; Hair et al., 2012b; Hair et al., 2014; Henseler et al., 2009; Hair et al., 2011). The indicator reliability is composed of the loading and the t-statistic. The loading of an indicator depicts the relationship between the indicator and should be greater than 0.7 (Chin, 1998a; Hair et al., 2014). The t-statistic demonstrates the significance level of an indicator (Huber et al., 2007). For a level of 10%, the t-statistic has to exceed the threshold of 1.65, for 5% of 1.96 and for 1% of 2.57 (Hair et al., 2014). Indicators which do not meet these or the following criteria must be eliminated from the model.

For fulfilling the convergence criterion, three measures have to be checked: the average variance extracted (AVE), the composite reliability, and the Cronbach's alpha (Chin, 1998a; Huber et al., 2007; Weiber and Mühlhaus, 2014). The AVE of a reflective construct has to explain, on average, "more than a half of the variance of its indicators" (Hair et al., 2014). Therefore, it has to exceed the value of 0.5 (Fornell and Larcker, 1981). The composite reliability of a construct indicates how accurately the indicators measure the construct and must exceed the limit of 0.7 (Nunally and Bernstein, 1994; Hair et al., 2014; Hair et al., 2011; Huber et al., 2007). Cronbach's alpha reflects the internal consistency of a construct (Cronbach, 1951; Nunally and Bernstein, 1994; Hair et al., 2014) and is required to exceed the threshold of 0.7 (Nunally and Bernstein, 1994; Hair et al., 2006 claims a limit of 0.6).

The discriminant validity indicates if constructs are sufficiently different. It covers the Fornell-Larcker criterion and the cross loadings. The Fornell-Larcker criterion is met if the AVE of a reflective construct is beyond all its squared correlations with the other constructs (Chin, 1998b; Fornell and Larcker, 1981; Hair et al., 2014). Concerning the cross loadings, the loadings of a construct's indicators must be higher on the construct itself than on any other construct of the SEM (Hair et al., 2014).

The predictive validity of a reflective construct shows if the data points of the construct's indicators are well predicted. It is covered by Stone-Geisser's Q^2 ($1 - SSE/SSO$ Communality) that has to exceed the threshold of zero (Chin, 1998b).

For the assessment of formative constructs, the significance of the indicators, the discriminant validity, and the test on multicollinearity have to be considered. To analyse the significance of the indicators, the weights have to be greater than 0.1 (Chin, 1998b; Huber et al., 2007) or smaller than -0.1 (Sarstedt et al., 2014). At the same time the t-statistics have to comply with the same constraints as reflective constructs (10%: 1.65, 5%: 1.96, 1%: 2.57). Concerning the discriminant validity, the correlation between a formative construct and all other constructs of the model is investigated. The threshold for this criterion is 0.9 (Huber et al., 2007).

To ensure that the analysis leads to reliable results and that the influence of the individual indicators are distinguishable, multicollinearity between indicators of formative constructs is not permitted (Diamantopoulos and Riefler, 2008; Diamantopolus and Winklhofer, 2001; Weiber and Mühlhaus, 2014; Henseler et al., 2009). For this, the variance inflation factor (VIF) for all indicators i , with $VIF_i = 1/(1 - R_i^2)$, (Sarstedt et al., 2014) should not exceed the given threshold of 5 (Hair et al., 2014; Hair et al., 2011). In addition, to ensure that there is no distortion of the weights because of undetected multicollinearity of formative constructs, by means of VIF_i , the condition indices are required to be below 30 (Hair et al., 2014; Henseler et al., 2009; Hair et al., 2012a).

Because formative constructs are built by their indicators, indicators that do not meet these criteria, except for multicollinearity, cannot be eliminated. Otherwise, the elimination of an indicator would

cause a change of the statistical values and the theoretical meaning of the belonging construct (Bollen and Lennox, 1991; Jarvis et al., 2003).

Following the guidelines of Jarvis et al. (2003), our SEM consists of four reflective (*Intention to Use, Attitude, Subjective Norm, Trust in Energy Provider*) and two formative (*Perceived Advantages, Perceived Disadvantages*) constructs.

Beginning with the reflective constructs, the indicator reliability is given for all constructs at a significance level of 1% (see Table 1). Concerning the convergence criterion, the AVE is greater than 0.5 for all constructs, the composite reliability exceeds the threshold of 0.7, and Cronbach's alpha is beyond the critical value of 0.7. Having a look at the discriminant validity, the squares of the highest correlations of a construct on *Intention to Use, Attitude, Subjective Norm* and *Trust in Energy Provider* are smaller than the respective AVEs (see Table 2). Thus, the reflective constructs share more variance with their appropriate indicators than with other constructs (Segars, 1997; Hair et al., 2014; Venkatraman, 1989) so that the Fornell-Larcker criterion is met. Because all loadings of each construct are lower on other constructs than on their belonging constructs (see Table 3), the reflective constructs differ sufficiently from the other constructs. Also the predictive validity is fulfilled for each construct so that a prediction of the latent variables is obtained through their indicators.

Construct	Indicator	loadings/ weights	t-statistic	signifi- cance	VIF	AVE	Composite Reliability	Cronbach's Alpha
Intention to Use	I1	0.9400	149.0105	***		0.8150	0.9294	0.8852
	I2	0.9379	143.8034	***				
	I3	0.8257	38.6863	***				
Attitude	A1	0.9257	95.4850	***		0.8155	0.9464	0.9242
	A2	0.9152	77.9218	***				
	A3	0.9190	62.8756	***				
	A4	0.8502	49.1167	***				
Subjective Norm	SN1	0.7790	23.9522	***		0.7286	0.8892	0.8115
	SN2	0.8839	53.5716	***				
	SN3	0.8932	48.7876	***				
Trust in Energy Provider	T1	0.9351	92.9728	***		0.8735	0.9539	0.9275
	T2	0.9525	145.8931	***				
	T3	0.9159	84.3386	***				
Perceived Advantages	PA1	0.0403	0.4450	ns	3.0488			
	PA2	0.4143	4.3221	***	3.1153			
	PA3	0.3885	5.9814	***	1.3793			
	PA4	0.5029	8.2556	***	1.2739			
Perceived Disadvantages	PD1	0.0064	0.0816	ns	1.8315			
	PD2	0.2642	3.2026	***	1.9881			
	PD3	0.0967	1.4943	ns	1.3736			
	PD4	0.3282	4.7738	***	1.4663			
	PD5	0.4348	5.5834	***	1.8051			
	PD6	0.1578	2.3810	**	1.4388			
	PD7	0.1244	1.8718	ns	1.7182			

Table 1. Significance of indicators; ns=not significant; * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

Construct	Highest Correlation to other Constructs	Squared Correlation	AVE
Intention to Use	0.8735	0.7630	0.8150
Attitude	0.8735	0.7630	0.8155
Subjective Norm	0.4650	0.2162	0.7286
Trust in Energy Provider	0.5421	0.2938	0.8735

Table 2. Fornell-Larcker Criterion

The analysis of the formative constructs shows that a few indicators of different constructs are not significant as either their t-statistic or their weight is below the required threshold (see Table 1). In more detail, regarding the construct *Perceived Advantages* one (PA1) of four indicators is not significant. Two (PD1 and PD3) non-significant indicators occur among the seven indicators in the construct *Perceived Disadvantages*. Except for one indicator (PD6) with a significance level of 5%, all other indicators are significant at the 1%-level. As there is no indication for multicollinearity (for all indicators $VIF < 5$ and condition index < 30) and therefore all indicators are sufficiently different and independent, no indicator must be dropped. Also the discriminant validity is given for the formative constructs as the highest latent variable correlation that occurs between *Perceived Advantages* and *Attitude* is 0.7212 and therefore beyond the claimed maximum of 0.9.

Indicator	Attitude	Intention to Use	Perceived Advantages	Perceived Disadvantages	Subjective Norm	Trust
A1	0.9257	0.7862	0.6925	-0.5703	0.3993	0.5113
A2	0.9152	0.7520	0.6687	-0.5522	0.4114	0.5337
A3	0.9190	0.8617	0.6871	-0.6524	0.4069	0.4878
A4	0.8502	0.7484	0.5483	-0.5665	0.4686	0.4230
I1	0.8526	0.9400	0.6749	-0.6605	0.4434	0.5105
I2	0.8171	0.9379	0.6651	-0.5851	0.4481	0.4971
I3	0.6845	0.8257	0.5404	-0.5226	0.3390	0.4494
SN1	0.3802	0.4031	0.3524	-0.3206	0.7790	0.3287
SN2	0.4145	0.3954	0.3968	-0.3353	0.8839	0.2791
SN3	0.3916	0.3683	0.3089	-0.3041	0.8932	0.2561
T1	0.5058	0.4966	0.4431	-0.5255	0.3186	0.9351
T2	0.4830	0.4716	0.4302	-0.5691	0.3101	0.9525
T3	0.5290	0.5390	0.4600	-0.5922	0.3216	0.9159

Table 3. Cross Loadings

4.3 Structural Model

The evaluation of the structural model concerns the assessment of the constructs and the paths between them, i.e. the hypotheses. The explanatory power of the model is described by the coefficient of determination R^2 that results from a regression analysis. It is said to be 'substantial' if $R^2 \geq 0.67$, 'moderate' if $R^2 \geq 0.33$, and 'weak' if $R^2 \geq 0.19$ (Chin, 1998b). To ensure reliable results for the structural model, multicollinearity between the constructs is not allowed (Huber et al., 2007; Hair et al., 2006; Hair et al., 2012a). The calculation and thresholds are the same as described in the previous section. For the assessment of the hypotheses, the path coefficients and the t-statistics have to be examined. The path coefficient must be greater than 0.1 or lower than -0.1 (Lohmöller, 1989; Sarstedt et al., 2014; Weiber and Mühlhaus, 2014; Chin, 1998a claims a limit of 0.2). The significance level of a path

is determined by the t-statistic. The same thresholds apply as for the significance of indicators (10%: 1.65, 5%: 1.96, 1%: 2.57).

The results of our model are as follows. The R^2 value is substantial for our target construct *Intention to Use* ($R^2=0.786$). *Attitude* ($R^2=0.64$) and *Perceived Disadvantages* ($R^2=0.397$) achieve a moderate level. *Perceived Advantages* ($R^2=0.3$) achieves a weak level. The VIF indicates that there is neither multicollinearity nor a condition index higher than 30 (Huber et al., 2007; Hair et al., 2006; Hair et al., 2012a). Regarding the structural relationships between the constructs, we found support for ten of eleven hypotheses. The constructs *Attitude* and *Perceived Advantages* are found to be positively related to *Intention to Use* (H1, H2b) with a significance level of 1%. The path coefficient between the constructs *Subjective Norm* and *Perceived Disadvantages*, *Trust in Energy Provider* and *Perceived Disadvantages*, *Perceived Disadvantages* and *Attitude*, and *Perceived Disadvantages* and *Intention to Use* are below -0.10 which implicates a negative relation between the constructs (H4b, H6c, H3a, H3b) with a significance level of 1%. The hypotheses H2a, H4a, H6a and H6b could be confirmed with a positive influence and a significance level of 1% whereas H5 is not supported by our data. Figure 2 shows the hypotheses with their path coefficients, significance, and effect sizes f^2 . For each construct, the R^2 and the predictive relevance Q^2 is provided.

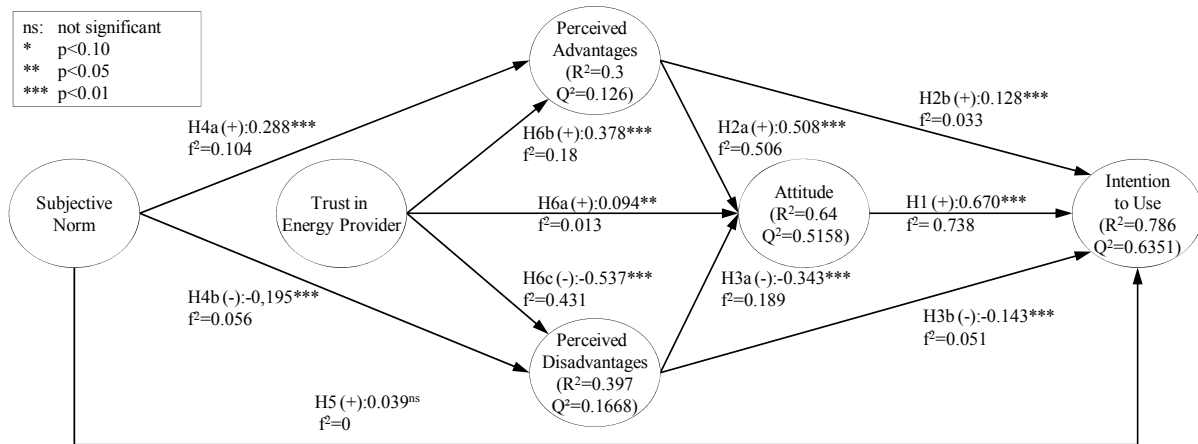


Figure 2. Results of the SEM – coefficient of determination R^2 , predictive relevance Q^2 , effect size f^2

5 Discussion

5.1 Conclusion

The results of our study are very satisfactory. Only one hypothesis (H5) out of eleven could not be confirmed, a second one is at a very weak level but still significant. In addition, the explanatory power of the model is substantial, explaining more than 78% of the variance. The aim of this paper was to analyse factors that drive or inhibit consumers to participate in direct load control and load shifting. Several advantages and disadvantages of DLC were derived from previous literature and have been analysed for their impact on the acceptance of DLC and LS. In particular, we focused on the role of the energy supplier and the consumers’ trust towards him.

Concerning our first research question “What drives consumers to accept or refuse load shifting of home appliances?” several driving and inhibiting factors could be found. Among the advantages, the ecological impact (PA4) has the highest influence followed by increased comfort (PA2) and financial benefits (PA3). This is in line with previous, mostly qualitative studies that identified financial benefits and ecological reasons as the most relevant advantages (Annala et al., 2012; Hargreaves et al., 2010; Mert et al., 2008; Paetz et al., 2012). But in contrast to these studies, the impact of financial benefits is lower than that of the other two factors. A reason is that consumers are sceptical if they

would profit financially from DLC. Only 7% expect a financial pay-off (“totally agree” and “mostly agree”), but 55% do not (“totally disagree” and “mostly disagree”). Concerning the ecological reasons, the picture is inverted. While 40% of the respondents agree to these benefits, only 14% do not. The increased comfort is perceived by 21%, 40% dissent. Only the increased efficiency for home tasks (PA1) could not be confirmed as a significant advantage although 20% ascribe this to DLC, but 40% do not.

The analysis of the disadvantages draws an ambiguous picture. Although 55% of the respondents expect that their usage profile will be used for other purposes (PD1), while only 7% do not (the highest and lowest values for all disadvantages), this disadvantage besides PD3 and PD7 could not be proven to be significant for the perceived disadvantages. Any other disadvantage is significant, but being unable to plan (PD6) has only a weak effect. The opinion concerning PD6 is balanced (24% vs. 27%). Among all disadvantages, loss of control (PD5) shows the highest impact (34% vs. 21%), followed by technical safety (PD4: 43% vs. 17%) and not well protected usage profiles (PD2: 52% vs. 7%). That means although privacy risks are said to be most important (Annala et al., 2012; Balta-Ozkan et al., 2013), only one risk (PD2) has a high impact while another has only a very low one (PD3) and the third is not significant (PD1). The reason could be that consumers are already used to the situation that much data about them is gathered and that this private data is constantly exposed to risks like misuse, disclosure, or other misappropriation.

To answer the second research question “Which role does trust towards the energy supplier play for participating in load shifting?”, we integrated the concept of trust into the research model and linked the trust towards the energy provider to attitude (H6a), advantages (H6b), and disadvantages (H6c). Interestingly, trust does not play a role for the attitude of consumers towards DLC but only for the perceived advantages and disadvantages. In particular, trust in the energy provider has a higher impact on the perceived disadvantages than on the advantages, but the advantages are more important for the attitude towards DLC than the disadvantages are. The reason may be that although the opinion concerning the energy provider is balanced (about 20% positive vs. 26% negative), there is a slight tendency to mistrust. This enforces the perceived disadvantages. But if consumers perceive the advantages of DLC and LS, this perception leads to a more positive attitude than disadvantages reduce the attitude. However, the influence of trust on attitude via advantages is only slightly lower than via disadvantages.

Overall, the research model confirmed well approved hypotheses and constructs of TAM and successive acceptance models. But interestingly, the relation between subjective norm and intention to use could not be confirmed while its impact on advantages and disadvantages could. A possible explanation is that energy management takes place in a private environment where usage behaviour can hardly be controlled by other people not living in the same household. Hence, the opinion of others forms the opinion about DLC and LS and therefore influences the perceived advantages and disadvantages, but does not impact the (intended) behaviour directly.

5.2 Implications

Several lessons can be learned from this study. First of all, although the privacy risk is a little bit less important than expected, it nevertheless plays an important role. In particular, energy providers should work on the data protection and communicate their efforts and measures to consumers. Concerning the technical safety, we observe a general misconception of consumers regarding home appliances that are remotely controlled like other studies do (Mert et al., 2008). Although such appliances are not more prone to technical risks than conventional appliances, respondents perceive that risk as high. Therefore, energy providers should better explain the concept of DLC and LS and that the technical risk does not increase but decreases on the contrary as appliances are then permanently monitored. Also, a new safety label for these appliances could help. Secondly, the perceived loss of control is the major problem for the diffusion of DLC and LS. Although this results from the core idea of DLC, energy providers can work on this problem by ensuring that the consumer remains the one who controls his appliances and that he does not hand over this control completely to the provider. Consumers should

always have the option to override control decisions of the energy provider so that they still have the feeling of being the one who “is wearing the pants around here”. Thirdly, energy providers should emphasise the increased comfort and the ecological advantages. As many consumers do not know or believe that DLC can improve the electrical system and therefore has positive impacts on the ecological environment (Mert et al., 2008; Paetz et al., 2012), better elucidation is needed. Concerning the comfort, energy providers could combine DLC with other services like notifications when the appliances have finished, additional maintenance etc. so that consumers perceive even more a gain in comfort. Fourthly, energy providers should provide enough financial benefits. Saving only a few cents is not attractive for consumers (Hargreaves et al., 2010). They should receive an adequate compensation for participating in such programs. Finally, energy providers should work on their reputation. Trust has been proven to be an important factor for the perception of advantages and disadvantages and therefore for the acceptance of DLR. But the perception of energy providers as being trustworthy is balanced at best so that there is much room for improvement.

Also for research, the results of this study provide several insights. First of all, the core of TAM and successive models could be confirmed but the subjective norm did not show an impact on the behavioural intention. That means that in contexts where the usage of an innovation cannot be monitored by others pressure from other people might not play such an important role. Secondly, our model shows that disadvantages act like an antipode to advantages or the usefulness of an innovation and should therefore be integrated in acceptance models. Thirdly, trust is an important factor for the perception of advantages and disadvantages. Its integration into the model improved the predictive power.

5.3 Limitations and Future Work

As always, several limitations have to be considered when interpreting the results. First of all, we must have a look at the sample. Although the number of participants was quite high, about 50% of the observations had to be eliminated due to incompleteness. In addition, the sample is to some extent biased. 70% of the respondents were male and only 30% were female. But women are still said to do most of the work in households and therefore are more responsible for participating in DLC. A similar bias can be observed in several other studies concerning smart metering (Chen et al., 2017; Chou et al., 2014; Kranz et al., 2010; Wunderlich et al., 2012b; Wunderlich et al., 2013). The reason for this phenomenon is that in households men are usually responsible for the decision making concerning energy (Wunderlich et al., 2012b; Wunderlich et al., 2013). Hence, they are most likely the ones who make the initial step to register for DLC programs. If this first step is made, the barrier for the following second step to allow and participate in DLC and LS is much lower than before. The reason for this gender bias in our study may also be that we worked together with an IT service provider and consulting firm that is active in the field of energy management. This may be the reason for the fact that many respondents were interested in this field and are disproportionately well educated. That means that less well educated people who account for a share of more than 50% of the German population (Statista, 2018) are underrepresented in this survey. Future work should focus on this population as the DLC and LS can only be successful if enough people are willing to participate. In spite of this educational bias, our sample has the advantage that in contrast to other studies (e.g. Kranz and Picot, 2011 and 2012) it comprises a wide range concerning age and employment and is not restricted to students. Furthermore, the sample might have a cultural bias as only German consumers participated in the survey. In other countries, the situation might be different, in particular in countries with a greater diffusion of smart meters. However, as Germany takes a pioneering role in the field of renewable energy, the role of German consumers is very important for the success of the energy turnaround. Secondly, DLC is still a theoretical concept in Germany and cannot be used. Therefore, even if the relation between intention and usage is found in many studies, this does not necessarily mean that the intention to participate in DLC of about 20% will also hold at the same level for the later usage. Therefore, future work should focus on the question which incentives are needed and how people can be triggered to participate in DLC and LS.

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