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FCN Working Paper No. 1/2015

Beyond Technology Adoption: Homeowner Satisfaction with Newly Adopted Residential Heating Systems

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Publisher: Prof. Dr. Reinhard Madlener
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Beyond Technology Adoption: Homeowner Satisfaction with Newly Adopted Residential Heating Systems

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Abstract

In this paper we study homeowner satisfaction with respect to innovative residential heating systems. In particular, we focus on the role of attributes of the home, homeowners' socio-demographic characteristics, RHS-related knowledge, and adoption motivations. For this purpose, we apply a linear regression model on a dataset obtained from a survey among homeowners in Germany (N=2,135) that had adopted a RHS shortly before the survey was conducted. Moreover, we investigate differences between groups of homeowners by means of t-tests and ANOVA. Our research shows that the motivations for adopting an RHS are relevant factors explaining satisfaction with newly adopted RHS. Moreover, we find the degree of RHS-related knowledge relevant as well. Socio-demographic aspects – such as age, university degree, gender or income – are found to be less important. In particular, the preference to have an RHS that is compatible with daily habits and routines has a strong impact on satisfaction. We also find differences between groups of adopters. Specifically, adopters of a gas-fired condensing boiler or a heat pump are less satisfied than adopters of a wood pellet-fired boiler. The findings of this study may also contribute to a better understanding of factors influencing the word to mouth communication resulting in the uptake and diffusion of certain RHS over time.

Keywords: customer satisfaction; user satisfaction, post-adoption behavior; space heating

JEL Classification Nos.: C20, D12, O33, Q41

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1 Introduction

Fossil fuels such as natural gas or oil dominate the residential heating sector in Germany. However, the threat of climate change and the high dependency on energy imports require a more efficient use of heat and a shift to less carbon-intensive fuels for heating. Besides targeting the energy efficiency of buildings, the provision of heat by means of innovative residential heating systems (RHS) based on renewable energy sources is a key for achieving these goals. Nevertheless, the current stock of RHS in single-family and duplex houses in Germany is dominated by oil- and gas-fired boilers, whereas there are relatively few renewable RHS (BDH, 2014a). Data on the annual market shares of newly installed RHS show that in 2013 more than 80% of the new installations were still based on fossil fuels such as oil or gas (BDH, 2014b). While there has been an increasing tendency towards renewable RHS in newly built homes in recent years (also driven by legal obligations to cover a certain share of heat from renewable energy sources), fossil fuel RHS still lead the replacement installations in existing homes in Germany (Shell and BDH, 2013).

In order to achieve a higher uptake of renewable RHS, a better understanding of the decision processes underlying the homeowners' choices of RHS is needed. Recent research results identify behavioral aspects and framework conditions on the individual, home and regional level as main determinants (see e.g. Alberini et al., 2014; Braun, 2010; Lillemo et al., 2013; Michelsen and Madlener, 2012, 2013a,b; Sopha and Klöckner, 2011). Amongst others, the influence of peers such as family members, neighbors or colleagues is a significant determinant for RHS uptake (see e.g. Claudy et al., 2011; Michelsen and Madlener, 2012, 2013a,b; Nyrud et al., 2008; Scarpa and Willis, 2010; Sopha and Klöckner, 2011; Woersdorfer and Kaus, 2011). Thus, the word of mouth communication resulting from the experiences of earlier adopters plays a crucial role in the uptake and diffusion of innovative RHS. Satisfied adopters may be more likely to describe the RHS in positive terms and to recommend the system to other homeowners. This may have both a direct and an indirect impact on the decision in favor of an innovative RHS. Hence, high levels of satisfaction may contribute to a broader and faster diffusion of innovative RHS in the long run.

Against this background, this research explores the factors that determine the satisfaction with newly adopted RHS including the gas- or oil-fired condensing boiler with solar thermal support, the heat pump, and the wood pellet-fired boiler. Therefore, the following questions guide our research: What determines the satisfaction with newly adopted RHS? What is the influence of the homes' attributes, the homeowners' socio-demographic characteristics, RHS-related knowledge, and adoption motivations? Are there any differences between groups of homeowners and types of RHS?

For the purpose of our research, we carried out a representative, self-administered mail survey. The participants were randomly selected owners of already existing or newly built single-family and duplex houses in Germany. The homeowners received a financial grant from Federal Office for Economic Affairs and Export Control (BAFA) between January 2009 and August 2010 to install a new RHS that was (at least partly) based on renewable energy sources. Our research is restricted to the four most frequently adopted types of RHS in Germany: oil- and gas-fired condensing boilers with solar thermal support (GAS-ST, OIL-ST), heat pump (HEAT-P), and wood pellet-fired boiler (WOOD). Hereby, we gathered a unique set of micro-data on the homeowners' actual adoption decisions.

Our empirical approach is based on a multiple linear regression model. We apply an ordinary least squares (OLS) model which is easy to apply and to interpret in our case. The dependent variable is the degree of homeowner satisfaction. As independent variables, we use socio-economic characteristics, the level of RHS-specific knowledge, and motivational factors behind the RHS adoption decision. This allows investigating differences between the expectations regarding certain attributes of the RHS (i.e. adoption motivations) before the adoption and the actual performance of the RHS after adoption. Moreover, this also allows controlling for the influence of the perceived level of RHS-specific knowledge when the adoption decision was taken, and for variables such as socio-economic and home characteristics.

To our knowledge, there exist only few empirical studies that investigate the determinants of homeowner satisfaction with newly adopted RHS. Examples include Bjørnstadt (2012), who explores the satisfaction of Norwegian households with heating systems such as heat pumps and wood pellet stoves, or Skejevrak and Sopha (2012), who investigate the satisfaction with wood pellet stoves in Norway.

The remainder part of this paper is structured as follows. Section 2 gives an overview of the relevant theoretical and empirical literature on user satisfaction and the role of word of mouth communication in the diffusion process. Section 3 presents the data, the model, and the empirical methodology applied for the purpose of this research. The results are presented and discussed in section 4. Finally, section 5 concludes and provides some scope for further research and also some recommendations for policy-makers and businesses.

2 Literature review

User or customer satisfaction is a measure of how products and services supplied by a company meet or exceed customer or user expectation. It is defined as "the number of customers, or percentage of total customers, whose reported experience with a firm, its products, or its services (ratings) exceeds specified satisfaction goals." (Farris et al., 2010, p. 57).

Customer satisfaction has its roots in the marketing and consumer behavior literature. Traditionally, it has been viewed as a relative concept. This implies that satisfaction (i.e. the state after the adoption or usage of a product) is always judged against a standard (i.e. state prior to adoption or usage of a product). A number of different and competing theories and models have been developed for analyzing user satisfaction.

Satisfaction models can be categorized into macro and micro models (Hom, 2000). Macro models integrate customer satisfaction in a network of related concepts, such as value, quality, complaining behavior, and loyalty. Micro models of customer satisfaction include elements that explain the composition of customer satisfaction. Such elements include expectations, equity, attribution, affect, and regret. In particular, micro models are used for operationalizing measurements of customer satisfaction. An example of a micro-model includes the Expectation-Disconfirmation model (also known under the term “Expectancy-Disconfirmation Paradigm” - EDP) developed by Oliver (1977). This model so far received the widest acceptance among researchers and is still widely used.

The EDP is based on the comparison of customers’ expectations and their perceived performance ratings. Specifically, an individual’s expectations are confirmed when a product performs as expected. It is negatively confirmed, when a product performs more poorly than expected. The disconfirmation is positive when a product performs better than the expectations (Churchill and Suprenant 1982). There are four constructs to describe the EDP, including expectations regarding the product, actual performance of the product, negative or positive disconfirmation of the expectations, and the resulting satisfaction of the customer. Thus, satisfaction is considered as an outcome of purchase and use, stemming from the comparison of expected rewards and incurred costs of the purchase in relation to the anticipated consequences.

Empirical research on energy consumer satisfaction cover studies on the overall satisfaction of consumers in the energy sector (e.g. Fiorio and Florio, 2011, on consumers’ satisfaction with electricity prices in the EU; Mutua et al., 2012, on consumers satisfaction in the energy sector in Kenya), or more specific studies, which mostly dealt either with the satisfaction with certain

services (e.g. Cravioto et al., 2014, on energy service satisfaction in Mexican communities) or technologies (e.g. Komatsu et al., 2013, on user satisfaction with rural home systems in Bangladesh; Mlecnik et al., 2012, on end-user experiences in nearly zero-energy houses).

For RHS, there exists relative little published research on user satisfaction. In general, Sopha et al. (2010) show that adopters who indicated to choose again a wood pellet boiler in the future by and large seem to be satisfied with their existing wood pellet boilers. Mahapatra et al. (2007) reveal that the emergence of low quality and expensive boilers on the market negatively influenced the satisfaction of early adopters. Nyrud et al. (2008) showed that satisfaction towards wood pellet boilers can help to predict the future use and willingness to recommend such an RHS to others. Thus, early adopters of wood pellet heating systems seem to be likely to pass their experience on to others, and hence influence future market penetration. This underlines again the importance to explore factors influencing the satisfaction or dissatisfaction with RHS.

Studies that investigate the satisfaction of RHS adopters in more detail include Skjevrak and Sopha (2012) and Bjørnstad (2012). Skjevrak and Sopha (2012) study early adopters' satisfaction with wood pellet heating systems in Norway. Their findings show that economic factors (i.e. costs) and technical factors (i.e. performance of the boiler) significantly influence the overall satisfaction of early adopters. Specific problems that early adopters experienced include igniter failure in the pellet stove, lack of committed and competent suppliers and vendors, more time and effort than expected during maintenance, and fines from pellets both during handling and combustion. Bjørnstad (2012) studies the overall satisfaction of Norwegian households participating in a subsidy program with newly installed RHS such as heat pumps and wood pellet boilers. The results show that differences in the economic returns between the heat pump and the wood pellet boiler do not influence satisfaction. The only economic variable found to impact investment satisfaction was the electricity price. Further variables explaining satisfaction of households include technical quality, indoor climate and heat comfort, and satisfaction with the supplier and service provided of the heating equipment. Nyrud et al. (2008) show for Norway that the satisfaction with wood pellet boilers is mainly related to the performance of the device. Moreover, time and effort required for operation and maintenance were found to have a negative influence on satisfaction.

3 Methodology and data

3.1 Survey development and implementation

The data analyzed in this paper stem from survey responses of owners of existing single-family and duplex houses in Germany who replaced their old oil- or gas-fired RHS between January 2009 and August 2010, either by a new gas- or oil-fired condensing boiler with solar thermal support (GAS-ST, OIL-ST), a heat pump (HEAT-P), or a wood pellet-fired boiler (WOOD). It represents a subsample of a representative mail survey conducted in 2010 among owners of newly built and existing single-family and duplex houses that received a capital grant from BAFA for the installation of a new RHS. For details of the survey, see Michelsen and Madlener (2012). A discussion of possible limitations related to the survey can be found in Michelsen and Madlener (2012, 2013a).

The questionnaire contained questions about the installed RHS and the determinants of the motivation to adopt an RHS. Survey participants were asked to report their agreement with selected statements regarding the perceived performance and characteristics of the RHS prior to the adoption decision. Furthermore, they were asked to report their satisfaction with the RHS adopted on a 5-point Likert scale (1 = "completely disagree" to 5 = "completely agree" or 1 = "unimportant" to 5 = "very important"). Finally, the survey participants were asked about selected attributes of their homes and socio-demographic characteristics.

The questionnaire was mailed to 5000 randomly selected homeowners who had received a BAFA grant. 2985 questionnaires were returned, which corresponds to an overall response rate of 59.7%. We excluded all observations where large sections of the questionnaire had not been filled out (or the questionnaire had not been filled out at all), where the owner did not live in but let the home (i.e. no self-usage), where there was a multi-family house, or where the installed main RHS was not a gas- or oil-fired condensing boiler, a heat pump, or a wood pellet-fired boiler. This reduced the gross sample to N = 2616 observations. Finally, we excluded 481 cases where at least one of the variables needed for the analysis was missing (casewise deletion). Therefore, the net sample for our analysis consisted of N = 2135 observations.

3.2 Model specification and analysis procedure

The analysis of the data is divided into two parts. In a first step, we conduct an OLS regression in order to identify determinants that help explaining the satisfaction with a newly adopted RHS. In a second step, we investigate differences between groups of adopters and types of RHS by means of ANOVA and t-tests.

The homeowner's overall satisfaction with the adopted RHS is operationalized by three items measuring different aspects of satisfaction. We measure the items on a 5-point Likert scale. The reliability of this scale is high for the full sample as well as for the two subsamples (Cronbach's alpha for the full sample: 0.906). Thus, the three items are well-suited for measuring the overall satisfaction with a newly adopted RHS (table 1). Table 2 displays the summary statistics for the independent variables.

Table 1: Summary statistics of the dependent variable for the full sample, sample of existing homes, and sample of newly built homes

		Full sample *N*=2135		**Existing homes** *N*=1238		**Newly built homes** *N*=897	
		Mean	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**
Item wording	From today's perspective, I would choose the same RHS again.	4.46	.761	4.51	.742	4.39	.782
	My expectations regarding the RHS were squarely fulfilled.	4.24	.797	4.29	.798	4.18	.792
	From today's perspective, I would recommend the RHS to others.	4.33	.806	4.37	.804	4.28	.807
Scale statistics	Cronbach's alpha	.906		.903		.907	
	Mean	4.35		4.39		4.28	
	S.D.	.723		.716		.729	

Table 2: Summary statistics of the independent variables

Characteristic	Category	Full sample *N*=2135		Existing homes *N*=1238		Newly built homes *N*=897	
Adopted RHS	*GAS-ST*	27.9%		26.5%		29.9%	
	OIL-ST	10.1%		17.0%		0.7%	
	HEAT-P	36.9%		19.5%		60.4%	
	WOOD	25.1%		36.7%		9.0%	
Previous RHS same				38.7%			
Female		16.3%		13.7%		20.1%	
University degree		36.0%		29.9%		44.4%	
Monthly net income of the household	*< €2000*	12.7%		16.7%		7.2%	
	€2000-2999	31.3%		34.1%		27.5%	
	€3000-3999	27.5%		23.5%		33.0%	
	€4000-4999	15.2%		13.7%		17.3%	
	€5000-5999	6.7%		6.3%		7.4%	
	> €6000	6.5%		5.7%		7.6%	
		Mean	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**
Age of the adopter		48.11	12.55	53.48	11.55	40.71	9.83
Costs		2.73	.92	2.87	.91	2.55	.90
Attitude		4.02	.64	4.04	.66	4.00	.61
BAFA		2.41	1.00	2.61	.99	2.12	.95
Threats		3.94	.09	3.95	.87	3.92	.91
Comfort		3.17	.95	3.12	.96	3.23	.94
Peers		2.24	.79	2.25	.80	2.23	.78
Knowledge		3.10	1.04	3.13	1.07	3.06	1.01

As independent variables for the regression analysis, we use socio-economic characteristics as control variables, the level of RHS-specific knowledge (i.e. perceived familiarity with the oil- or gas-fired condensing boiler, heat pump, or wood pellet-fired boiler), and motivational factors behind the RHS adoption decision (cost considerations, perceived usability and compatibility with existing habits and norms, capital grant from the government, reactions to external threats such as environmental protection and independence from fossil fuels, comfort considerations, and influence of peers such as family, friends or neighbors). The six variables describing motivational factors are based on Michelsen and Madlener (2013a) and consist of three to six items each. We investigate three different samples. The sample includes all observations, whereas the other two only include newly built homes or existing homes, respectively. The subsample of existing homes also contains a variable that indicates whether the previous RHS was of the same type.

4 Results

This section presents the results from the regression analysis that explores possible factors influencing the satisfaction with an adopted RHS. Finally, we present insights from the ANOVA and *t*-tests.

Table 3 displays the results of the regression analysis. In a first step, we discuss the results for the full sample. Based on that, we briefly present differences that we found in the subsamples of existing homes and newly built homes.

In general, we find that the R^2 of all three models is in the lower range. This implies that there may be additional variables explaining the satisfaction with the RHS after the adoption decision. Examples of such variables include the *ex-post* evaluation of technical attributes and the performance of the RHS during operation (i.e. experienced problems and benefits). However, our questionnaire had a focus on the adoption decision and did not include any items on an *ex-post* evaluation of the RHS.

Table 3: Results of the linear regression analysis

	Full sample		**Subsample 1 Existing homes**		**Subsample 2 Newly built homes**	
	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
(CONSTANT)	**1.654** ***	**0.124**	**1.911** ***	**.179**	**1.371** ***	0.194
COSTS	-0.014	0.017	-.033	.022	0.006	0.026
ATTITUDE	**0.537** ***	**0.022**	**.515** ***	**.029**	**0.564** ***	0.036
BAFA	0.001	0.015	**.036** *	**.021**	**-0.053** **	0.024
THREATS	**0.078** ***	**0.016**	**.049** **	**.024**	**0.121** ***	0.024
COMFORT	**-0.033** **	**0.015**	**-.060** ***	**.020**	0.012	0.024
PEERS	**0.047** ***	**0.018**	**.045** *	**.023**	**0.050** *	0.027
KNOWLEDGE	**0.053** ***	**0.014**	**.058** ***	**.018**	**0.045** **	0.023
UNIVERSITY	**-0.122** ***	**0.031**	**-.140** ***	**.043**	**-0.101** **	0.045
FEMALE	0.013	0.037	-.033	.053	0.076	0.052
AGE	**0.002** **	**0.001**	.002	.002	0.000	0.002
INCOME	0.009	0.011	.017	.015	0.005	0.017
PREV_RHS_SAME			.028	.042		
Pseudo-R^2	.267		.248		.298	
N	2135		1238		897	

Notes: Superscripts ***, ** and * indicate statistical significance at the 1%, 5% and 10% level, respectively.

The estimation results for the full sample show that the motivational factors ATTITUDE ($\hat{\beta}$ = 0.537***), THREATS ($\hat{\beta}$ = 0.078***), COMFORT ($\hat{\beta}$ = -0.033**) and PEERS ($\hat{\beta}$ = 0.047***) have a significant influence on the adoption decision. This means that the adoption motivations "general attitude towards the RHS" (i.e. perceived usability and compatibility with existing habits and norms), "reactions to external threats" (i.e. environmental problems and energy supply security considerations), and, the "influence of peers" (i.e. family, neighbors or colleagues) are positively confirmed after the adoption decision. In contrast, we find that adopters that are motivated by comfort considerations (i.e. fuel acquisition or ease of use) are less satisfied.

For KNOWLEDGE, we find a positive impact on the satisfaction with a RHS after adoption ($\hat{\beta}$ = 0.047***). This implies that a higher RHS-related knowledge at the point in time when the adoption decision is taken results in a higher satisfaction with the adopted RHS.

For the control variables, we find a negative impact of UNIVERSITY ($\hat{\beta}$ = -0.122***). This implies that adopters with a university degree tend to be less satisfied with the adopted RHS. A reason for that may be that adopters with a university degree are more critical than adopters without a university degree. For AGE, we find a small positive impact on satisfaction ($\hat{\beta}$ = 0.002**). Thus, older adopters are found to be more satisfied with the chosen RHS.

In general, the results for the subsample of existing homes reflect the findings for the full sample. Moreover, we find that homeowners that were motivated by the BAFA grant (BAFA, $\hat{\beta}$ = 0.036*) are more satisfied with the adopted RHS. Finally, we find that the included variable PREV_RHS_SAME (i.e. the previous RHS was of the same type as the newly adopted RHS) has a positive impact on satisfaction. However, this effect turns out to be statistically not significant.

For the subsample of newly built homes, we also find the results for the full sample to be reflected. However, the impact of the motivational factor "BAFA grant" on the adopter's satisfaction is found to be negative ($\hat{\beta}$ = -0.053**). A reason for that may be that the grant for adopters with newly built homes is lower than for existing homes. Moreover, the variable COMFORT turns out to be statistically not significant.

In order to detect possible differences in the degree of satisfaction between groups of homeowners and types of RHS, we conducted ANOVA and *t*-tests. For this purpose, we segmented the full sample and the two subsamples by the following variables: type of adopted RHS (GAS-ST, OIL-ST, HEAT-P, WOOD), existing or newly built home (only full sample), adopted RHS same as previous one (only subsample of existing homes), adopter is older than 65, adopter is younger than 40, income of the household, adopter has a university degree, adopter is a female, and spatial variables (i.e. home is located in a rural region, in the East, or in the South of Germany). In the following, we present the results for the full sample and focus the presentation on significant results.

The findings show that there are statistically significant differences in satisfaction between the types of adopted RHS ($F(3, 2131) = 8.57$, $p < 0.01$). Generally, adopters of WOOD seem to be more satisfied with their RHS. In particular, there are statistically significant differences in the means (μ) for WOOD (μ = 4.47) and GAS-ST (μ = 4.25) and between WOOD (μ = 4.47) and HEAT-P (μ =

4.34). A possible reason may be that adopters of WOOD as a green technology are often more engaged in the adoption decision.

Moreover, we find statistically significant differences between adopters with and without a university degree ($t(2133) = 3.28$, $p < 0.01$, two-sided). Adopters with a university degree ($\mu = 4.28$) seem to be less satisfied than adopters without a degree ($\mu = 4.38$). As already discussed above, this may reflect that adopters with a university degree are apparently more critical than adopters without a university degree.

For the type of home ($t(2133) = 3.45$, $p < 0.01$, two-sided), we find that owners of existing homes ($\mu = 4.39$) are statistically significant more satisfied than owners of newly built homes ($\mu = 4.28$). This may reflect the intuition that owners of existing homes appreciate that they now have a more up-to-date and well-functioning RHS.

We find marginally significant differences between adopters that have their home located in the South of Germany or in the rest of Germany ($t(2116) = -1.92$, $p < 0.1$, two-sided). Adopters in the South are found to be more satisfied with the adopted RHS ($\mu = 4.39$) than adopters in the remaining part of Germany ($\mu = 4.32$). An explanation may be differences in the temper of the adopters coming from different regions in Germany.

5 Discussion and Conclusions

Fossil fuels such as natural gas or oil are the most common fuels for residential space heating in Germany. However, the threat of climate change or the high dependency on energy imports require a more efficient provision and use of heat as well as a shift to less carbon-intensive fuels for heating. Besides targeting the energy efficiency of buildings, the provision of heat by innovative RHS based on renewable energy sources is a key for dealing with these problems. Among others, the word of mouth communication resulting from the experiences of earlier adopters plays a crucial role in the uptake and diffusion of innovative RHS. Satisfied adopters are more likely to describe the RHS in positive terms and to recommend the system to other homeowners. Hence, high levels of satisfaction may contribute to a broader and faster diffusion of RHS in the long run. Therefore, this research explores the factors that determine the satisfaction with newly adopted RHS. For this purpose, we analyzed data from a 2010 questionnaire survey of owners of existing single-family and duplex houses that received a financial grant to install a (partly) renewable RHS.

Our research shows that the motivations for adopting an RHS are relevant factors explaining satisfaction with newly adopted RHS. Moreover, we find the degree of RHS-related knowledge also

to be a relevant factor. Socio-demographic aspects such as age, university degree, gender or income are found to be less important. In particular, the preference to have an RHS that is compatible to daily habits and routines (i.e. variable ATTITUDE) has a strong impact on satisfaction. Thus, homeowners with such a motivation during the adoption decision are less likely to be dissatisfied afterwards because the RHS does not match with their routines and requirements. Adopters with a higher degree of RHS-related knowledge are also more likely to be satisfied with their newly adopted RHS. This shows that informed homeowners may be less likely to be surprised by unanticipated aspects or attributes of the adopted RHS. These results show that an RHS has to fit to the adopters needs and that adopters have to be informed about possible RHS choices in order to be satisfied afterwards. Thus, on a more general level, this research shows that homeowners have to be convinced about the adopted RHS in order to be satisfied afterwards.

We also find statistically significant differences between groups of adopters. In particular, adopters of GAS-ST and HEAT-P are less satisfied than adopters of WOOD. This shows the need to explicitly target these two groups of adopters by policy-makers or marketing strategies of RHS manufacturers.

This research has also some limitations. The statistical model may not cover all relevant factors explaining the satisfaction with an adopted RHS. Therefore, further research should be undertaken that explicitly targets the factors that may influence satisfaction. Examples of such variables may include the *ex-post* evaluation of technical attributes and the performance of the RHS during operation (i.e. experienced problems and benefits).

Finally, the findings of this study may also contribute to a better understanding of the role of factors influencing the word to mouth communication resulting in the uptake and diffusion of certain RHS over time.

References

Alberini, A., Bigano, A. and Boeri, M. (2014), Looking for free riding: energy efficiency incentives and Italian homeowners, *Energy Efficiency*, 7(4), 571-590.

BDH - Bundesindustrieverband Deutschland Haus-, Energie- und Umwelttechnik e.V. (2014a), Gesamtbestand zentrale Wärmeerzeuger 2013, [Online] Available at: http://www.bdh-koeln.de/uploads/media/Pressegrafik_Gesamtzahl_Waermeerzeuger_2013.pdf [accessed January 31, 2015].

BDH – Bundesindustrieverband Deutschland Haus-, Energie- und Umwelttechnik e.V. (2014b), Bilanz Heizungsindustrie 2013, [Online] Available at: http://www.bdh-koeln.de/uploads/media/Bilanz_Heizungsindustrie_2013.pdf [accessed January 31, 2015].

Bjørnstad, E. (2012), Diffusion of renewable heating technologies in households. Experiences from the Norwegian Household Subsidy Programme, *Energy Policy*, 48(September), 148-158.

Braun, F. (2010), Determinants of households' space heating type: A discrete choice analysis for German households, *Energy Policy*, 38(10), 5493-5503.

Churchill, G.A. Jr. and Surprenant, C. (1982), An investigation into the determinants of customer satisfaction, *Journal of Marketing Research*, 19(November), 491 -504.

Claudy, M.C., Michelsen, C. and O'Driscoll, A. (2011), The diffusion of microgeneration technologies – assessing the influence of perceived product characteristics on home owners' willingness to pay, *Energy Policy*, 39(2), 1459-1469.

Cravioto, J., Yamasue, E., Okumura, H. and Ishihara, K.N. (2014), Energy service satisfaction in two Mexican communities: A study on demographic, household, equipment and energy related predictors, *Energy Policy*, 73(October), 110-126.

Farris, P.W.; Bendle; N.T.; Pfeifer, P.E. and Reibstein, D.J. (2010). *Marketing Metrics: The Definitive Guide to Measuring Marketing Performance.* Upper Saddle River, New Jersey: Pearson Education, Inc.

Fiorio, C.V. and Florio, M. (2011), "Would you say that the price you pay for electricity is fair?" Consumers' satisfaction und utility reforms in the EU 15, *Energy Economics*, 33(2), 178-187.

Hom, W. (2000), An Overview of Customer Satisfaction Models. *RP Group Proceedings*, 100–110.

Komatsu, S., Kaneko, S., Ghosh, P.P. and Morinaga, A. (2013), Determinants of user satisfaction with solar home systems in rural Bangladesh, *Energy*, 61(November), 52-58.

Lillemo, S.C., Alfnes, F., Halvorsen, B. and Wik, M. (2013), Households' heating investments: The effect of motives and attitudes on choice of equipment, *Biomass and Bioenergy*, 57(October), 4-12.

Mahapatra K., Gustavsson L., Madlener R. (2007), Bioenergy innovations: The case of wood pellet systems in Sweden, *Technology Analysis and Strategic Management*, 19(1), 99-125.

Mlecnik, E., Schütze, T., Jansen, S.J.T., Visscher, H.J. and Van Hal, A. (2012), End-user experiences in nearly zero-energy houses, *Energy and Buildings*, 49(June), 471-478.

Michelsen, C.C. and Madlener, R. (2012), Homeowners' preferences for adopting innovative residential heating systems: A discrete choice analysis for Germany, *Energy Economics*, 34(5), 1274-1283.

Michelsen, C. C. and Madlener, R. (2013a), Motivational factors influencing the homeowners' decisions between residential heating systems: An empirical analysis for Germany, *Energy Policy*, 57(June), 221-233.

Michelsen C.C., Madlener R. (2013b), Switching from fossil fuel to renewables in residential heating systems: An empirical study of homeowners' decisions in Germany, *FCN Working Paper* No. 14/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, October, [Online] Available at: http://ssrn.com/abstract=2413400.

Mutua, J., Ngui, D., Osiolo, H., Aligula, E. and Gachanja, J. (2012), Consumers satisfaction in the energy sector in Kenya, *Energy Policy*, 48(September), 702-710.

Nyrud, A.Q., Roos, A. and Sande, J.B. (2008), Residential bioenergy heating: A study of consumer perceptions of improved woodstoves, *Energy Policy*, 36(8), 3169-3176.

Oliver, R.L. (1977), Effect of expectation and disconfirmation on postexposure product evaluations: An alternative interpretation, *Journal of Applied Psychology*, 62(August), 480-486.

Scarpa, R. and Willis, K. (2010), Willingness to pay for renewable energy: primary and discretionary choice of British households' for micro-generation technologies, *Energy Economics*, 32(1), 129-136.

Shell and BDH – Shell Deutschland Oil GmbH and Bundesindustrieverband Deutschland Haus-, Energie- und Umwelttechnik (2013), Shell BDH Hauswärme-Studie. Klimaschutz im Wohnungssektor – Wie heizen wir morgen? Fakten, Trends und Perspektiven für Heiztechniken bis 2030, [Online] Available at: s08.static-shell.com/content/dam/shell-new/local/country/deu/downloads/pdf/comms-shell-bdh-heating-study-2013.pdf [accessed January 31, 2015].

Skjevrak, G. and Sopha, M. (2012), Wood-Pellet Heating in Norway: Early Adopters' Satisfaction and Problems That Have Been Experienced, *Sustainability*, 4(6), 1089-1103.

Sopha, B.M., Klöckner, C.A., Skjevrak, G. and Hertwich, E.G. (2010), Norwegian households' perception of wood pellet stove compared to air-to air heat pump and electric heating, *Energy Policy*, 38(7), 3744-3754.

Sopha, B.M. and Klöckner, C.A. (2011), Psychological factors in the diffusion of sustainable technology: A study of Norwegian households' adoption of wood pellet heating, *Renewable and Sustainable Energy Reviews*, 15(6), 2756-2765.

Woersdorfer, J.S. and Kaus, W. (2011), Will nonowners follow pioneer consumers in the adoption of solar thermal systems? Empirical evidence for northwestern Germany, *Ecological Economics*, 70(12), 2282-2291.

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2015

Michelsen C.C., Madlener R. (2015). Beyond Technology Adoption: Homeowner Satisfaction with Newly Adopted Residential Heating Systems, FCN Working Paper No. 1/2015, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February.

2014

Sunak Y., Madlener R. (2014). Local Impacts of Wind Farms on Property Values: A Spatial Difference-in-Differences Analysis, FCN Working Paper No. 1/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February (revised October 2014).

Garnier E., Madlener R. (2014). Leveraging Flexible Loads and Options-based Trading Strategies to Optimize Intraday Effects on the Market Value of Renewable Energy, FCN Working Paper No. 2/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February.

Kerres B., Fischer K., Madlener R. (2014). Economic Evaluation of Maintenance Strategies for Wind Turbines: A Stochastic Analysis, FCN Working Paper No. 3/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, March.

Loucao S., Madlener R. (2014). External Effects of Hydraulic Fracturing: Risks and Welfare Considerations for Water Supply in Germany, FCN Working Paper No. 4/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, April.

Popov M., Madlener R. (2014). Backtesting and Evaluation of Different Trading Schemes for the Portfolio Management of Natural Gas, FCN Working Paper No. 5/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May.

Madlener R., Reismann T. (2014). The Great Pacific Garbage Patch: A Preliminary Economic Analysis of the 'Sixth Continent', FCN Working Paper No. 6/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May.

Blum J., Madlener R., Michelsen C.C. (2014). Exploring the Diffusion of Innovative Residential Heating Systems in Germany: An Agent-Based Modeling Approach, FCN Working Paper No. 7/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, July.

Tejada R., Madlener R. (2014). Optimal Renewal and Electrification Strategy for Commercial Car Fleets in Germany, FCN Working Paper No. 8/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Galvin R., Madlener R. (2014). Determinants of Commuter Trends and Implications for Indirect Rebound Effects: A Case Study of Germany's Largest Federal State of NRW, 1994-2013, FCN Working Paper No. 9/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September.

Garbuzova-Schlifter M., Madlener R. (2014). Risk Analysis of Energy Performance Contracting Projects in Russia: An Analytic Hierarchy Process Approach, FCN Working Paper No. 10/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, October.

Kumar S., Madlener R., Suri I. (2014). An Energy System Analysis on Restructuring the German Electricity Market with New Energy and Environmental Policies, FCN Working Paper No. 11/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, October.

Rosen C., Madlener R. (2014). Regulatory Options for Local Reserve Energy Markets: Implications for Prosumers, Utilities, and other Stakeholders, FCN Working Paper No. 12/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, October.

Rosen C., Madlener R. (2014). Socio-Demographic Influences on Bidding Behavior: An Ex-Post Analysis of an Energy Prosumer Lab Experiment, FCN Working Paper No. 13/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Kumar S., Madlener R. (2014). A Least-Cost Assessment of the CO_2 Mitigation Potential Using Renewable Energies in the Indian Electricity Supply Sector, FCN Working Paper No. 14/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Kammeyer F., Madlener R: (2014). Income Distribution Effects of the German *Energiewende*: The Role of Citizen Participation in Renewable Energy Investments, FCN Working Paper No. 15/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Höfer T., Sunak Y., Siddique H., Madlener R. (2014). Wind Farm Siting Using a Spatial Analytic Hierarchy Process Approach: A Case Study of the Städteregion Aachen, FCN Working Paper No. 16/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Garnier E., Madlener R. (2014). Day-Ahead versus Intraday Valuation of Demand Side Flexibility for Photovoltaic and Wind Power Systems, FCN Working Paper No. 17/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Sluzalek R., Madlener R. (2014). Trade-Offs when Investing in Grid Extension, Electricity Storage, and Demand Side Management: A Model-Based Analysis, FCN Working Paper No. 18/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Galassi V., Madlener R. (2014). Identifying Business Models for Photovoltaic Systems with Storage in the Italian Market: A Discrete Choice Experiment, FCN Working Paper No. 19/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Illian K., Madlener R. (2014), Short-Term Energy Storage for Stabilizing the High Voltage Transmission Grid: A Real Options Analysis, FCN Working Paper No. 20/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Oberst C., Madlener R. (2014). Regional Economic Determinants for the Adoption of Distributed Generation Based on Renewable Energies: The Case of Germany, FCN Working Paper No. 21/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Oberst C., Madlener R. (2014). Prosumer Preferences Regarding the Adoption of Micro-Generation Technologies: Empirical Evidence for German Homeowners, FCN Working Paper No. 22/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Harmsen – van Hout M.J.W., Madlener R., Prang C.D. (2014). Online Discussion among Energy Consumers: A Semi-Dynamic Social Network Visualization, FCN Working Paper No. 23/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Madlener R., Heesen F., Besch G. (2014). Determination of Direct Rebound Effects for Building Retrofits from Energy Services Demand, FCN Working Paper No. 24/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Heesen F., Madlener R. (2014). Technology Acceptance as Part of the Behavioral Rebound Effect in Energy Efficient Retrofitted Dwellings, FCN Working Paper No. 25/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Schulz S., Madlener R. (2014). Portfolio Optimization of Virtual Power Plants, FCN Working Paper No. 26/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

2013

Grieser B., Madlener R., Sunak Y. (2013). Economics of Small Wind Power Plants in Urban Settings: An Empirical Investigation for Germany, FCN Working Paper No. 1/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, January.

Madlener R., Specht J.M. (2013). An Exploratory Economic Analysis of Underground Pumped-Storage Hydro Power Plants in Abandoned Coal Mines, FCN Working Paper No. 2/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February.

Kroniger D., Madlener R. (2013). Hydrogen Storage for Wind Parks: A Real Options Evaluation for an Optimal Investment in More Flexibility, FCN Working Paper No. 3/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February.

Petersen C., Madlener R. (2013). The Impact of Distributed Generation from Renewables on the Valuation and Marketing of Coal-Fired and IGCC Power Plants, FCN Working Paper No. 4/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February.

Oberst C.A., Oelgemöller J. (2013). Economic Growth and Regional Labor Market Development in German Regions: Okun's Law in a Spatial Context, FCN Working Paper No. 5/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, March.

Harmsen - van Hout M.J.W., Ghosh G.S., Madlener R. (2013). An Evaluation of Attribute Anchoring Bias in a Choice Experimental Setting. FCN Working Paper No. 6/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, April.

Harmsen - van Hout M.J.W., Ghosh G.S., Madlener R. (2013). The Impact of Green Framing on Consumers' Valuations of Energy-Saving Measures. FCN Working Paper No. 7/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, April.

Rosen C., Madlener R. (2013). An Experimental Analysis of Single vs. Multiple Bids in Auctions of Divisible Goods, FCN Working Paper No. 8/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, April (revised November 2013).

Palmer J., Sorda G., Madlener R. (2013). Modeling the Diffusion of Residential Photovoltaic Systems in Italy: An Agent-based Simulation, FCN Working Paper No. 9/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May.

Bruns S.B., Gross C. (2013). What if Energy Time Series are not Independent? Implications for Energy-GDP Causality Analysis, FCN Working Paper No. 10/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, June.

Bruns S.B., Gross C., Stern D.I. (2013). Is There Really Granger Causality Between Energy Use and Output?, FCN Working Paper No. 11/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Rohlfs W., Madlener R. (2013). Optimal Power Generation Investment: Impact of Technology Choices and Existing Portfolios for Deploying Low-Carbon Coal Technologies, FCN Working Paper No. 12/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Rohlfs W., Madlener R. (2013). Challenges in the Evaluation of Ultra-Long-Lived Projects: Risk Premia for Projects with Eternal Returns or Costs, FCN Working Paper No. 13/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Michelsen C.C., Madlener R. (2013). Switching from dFossil Fuel to Renewables in Residential Heating Systems: An Empirical Study of Homeowners' Decisions in Germany, FCN Working Paper No. 14/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, October.

Rosen C., Madlener R. (2013). The Role of Information Feedback in Local Reserve Energy Auction Markets, FCN Working Paper No. 15/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Himpler S., Madlener R. (2013). A Dynamic Model for Long-Term Price and Capacity Projections in the Nordic Green Certificate Market, FCN Working Paper No. 16/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Weibel S., Madlener R. (2013). Cost-effective Design of Ringwall Storage Hybrid Power Plants: A Real Options Analysis, FCN Working Paper No. 17/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Budny C., Madlener R., Hilgers C. (2013). Economic Feasibility of Pipeline and Underground Reservoir Storage Options for Power-to-Gas Load Balancing, FCN Working Paper No. 18/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Johann A., Madlener R. (2013). Profitability of Energy Storage for Raising Self-Consumption of Solar Power: Analysis of Different Household Types in Germany, FCN Working Paper No. 19/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Hackbarth A., Madlener R. (2013). Willingness-to-Pay for Alternative Fuel Vehicle Characteristics: A Stated Choice Study for Germany, FCN Working Paper No. 20/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Katatani T., Madlener R. (2013). Modeling Wholesale Electricity Prices: Merits of Fundamental Data and Day-Ahead Forecasts for Intermittent Power Production, FCN Working Paper No. 21/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Baumgärtner M., Madlener R. (2013). Factors Influencing Energy Consumer Behavior in the Residential Sector in Europe: Exploiting the REMODECE Database, FCN Working Paper No. 22/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Charalampous G., Madlener R. (2013). Risk Management and Portfolio Optimization for Gas- and Coal-Fired Power Plants in Germany: A Multivariate GARCH Approach, FCN Working Paper No. 23/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Mallah S., Madlener R. (2013). The Causal Relationship Between Energy Consumption and Economic Growth in Germany: A Multivariate Analysis, FCN Working Paper No. 24/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

2012

Ghosh G., Shortle J. (2012). Managing Pollution Risk through Emissions Trading, FCN Working Paper No. 1/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, January.

Palzer A., Westner G., Madlener M. (2012). Evaluation of Different Hedging Strategies for Commodity Price Risks of Industrial Cogeneration Plants, FCN Working Paper No. 2/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, March (revised March 2013).

Sunak Y., Madlener R. (2012). The Impact of Wind Farms on Property Values: A Geographically Weighted Hedonic Pricing Model, FCN Working Paper No. 3/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May (revised March 2013).

Achtnicht M., Madlener R. (2012). Factors Influencing German House Owners' Preferences on Energy Retrofits, FCN Working Paper No. 4/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, June.

Schabram J., Madlener R. (2012). The German Market Premium for Renewable Electricity: Profitability and Risk of Self-Marketing, FCN Working Paper No. 5/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, July.

Garbuzova M., Madlener R. (2012). Russia's Emerging ESCO Market: Prospects and Barriers for Energy Efficiency Investments, FCN Working Paper No. 6/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, July (revised September 2012).

Rosen C., Madlener R. (2012). Auction Design for Local Reserve Energy Markets, FCN Working Paper No. 7/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, July (revised March 2013).

Sorda G., Madlener R. (2012). Cost-Effectiveness of Lignocellulose Biorefineries and their Impact on the Deciduous Wood Markets in Germany. FCN Working Paper No. 8/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September.

Madlener R., Ortlieb C. (2012). An Investigation of the Economic Viability of Wave Energy Technology: The Case of the Ocean Harvester, FCN Working Paper No. 9/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, October.

Hampe J., Madlener R. (2012). Economics of High-Temperature Nuclear Reactors for Industrial Cogeneration, FCN Working Paper No. 10/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, October.

Knaut A., Madlener R., Rosen C., Vogt C. (2012). Effects of Temperature Uncertainty on the Valuation of Geothermal Projects: A Real Options Approach, FCN Working Paper No. 11/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Hünteler J., Niebuhr C.F., Schmidt T.S., Madlener R., Hoffmann V.H. (2012). Financing Feed-in Tariffs in Developing Countries under a Post-Kyoto Climate Policy Regime: A Case Study of Thailand, FCN Working Paper No. 12/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Blass N., Madlener R. (2012). Structural Inefficiencies and Benchmarking of Water Supply Companies in Germany, FCN Working Paper No. 13/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Madlener R., Schabram J. (2012). Predicting Reserve Energy from New Renewables by Means of Principal Component Analysis and Copula Functions, FCN Working Paper No. 14/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Harzendorf F., Madlener R. (2012). Optimal Investment in Gas-Fired Engine-CHP Plants in Germany: A Real Options Approach, FCN Working Paper No. 15/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Schmitz M., Madlener R. (2012). Economic Feasibility of Kite-Based Wind Energy Powerships with CAES or Hydrogen Storage, FCN Working Paper No. 16/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Dergiades T., Madlener R., Christofidou G. (2012). The Nexus between Natural Gas Spot and Futures Prices at NYMEX: Do Weather Shocks and Non-Linear Causality in Low Frequencies Matter?, FCN Working Paper No. 17/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December (revised September 2013).

Rohlfs W., Madlener R. (2012). Assessment of Clean-Coal Strategies: The Questionable Merits of Carbon Capture-Readiness, FCN Working Paper No. 18/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Wüstemeyer C., Bunn D., Madlener R. (2012). Bridging the Gap between Onshore and Offshore Innovations by the European Wind Power Supply Industry: A Survey-based Analysis, FCN Working Paper No. 19/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Fuhrmann J., Madlener R. (2012). Evaluation of Synergies in the Context of European Multi-Business Utilities, FCN Working Paper No. 20/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

2011

Sorda G., Sunak Y., Madlener R. (2011). A Spatial MAS Simulation to Evaluate the Promotion of Electricity from Agricultural Biogas Plants in Germany, FCN Working Paper No. 1/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, January (revised October 2012).

Madlener R., Hauertmann M. (2011). Rebound Effects in German Residential Heating: Do Ownership and Income Matter?, FCN Working Paper No. 2/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February.

Garbuzova M., Madlener R. (2011). Towards an Efficient and Low-Carbon Economy Post-2012: Opportunities and Barriers for Foreign Companies in the Russian Market, FCN Working Paper No. 3/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February (revised July 2011).

Westner G., Madlener R. (2011). The Impact of Modified EU ETS Allocation Principles on the Economics of CHP-Based District Heating Networks. FCN Working Paper No. 4/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February.

Madlener R., Ruschhaupt J. (2011). Modeling the Influence of Network Externalities and Quality on Market Shares of Plug-in Hybrid Vehicles, FCN Working Paper No. 5/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, March.

Juckenack S., Madlener R. (2011). Optimal Time to Start Serial Production: The Case of the Direct Drive Wind Turbine of Siemens Wind Power A/S, FCN Working Paper No. 6/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, March.

Madlener R., Sicking S. (2011). Assessing the Economic Potential of Microdrilling in Geothermal Exploration, FCN Working Paper No. 7/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, April.

Bernstein R., Madlener R. (2011). Responsiveness of Residential Electricity Demand in OECD Countries: A Panel Cointegration and Causality Analysis, FCN Working Paper No. 8/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, April.

Michelsen C.C., Madlener R. (2011). Homeowners' Preferences for Adopting Residential Heating Systems: A Discrete Choice Analysis for Germany, FCN Working Paper No. 9/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May (revised January 2012).

Madlener R., Glensk B., Weber V. (2011). Fuzzy Portfolio Optimization of Onshore Wind Power Plants. FCN Working Paper No. 10/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May.

Glensk B., Madlener R. (2011). Portfolio Selection Methods and their Empirical Applicability to Real Assets in Energy Markets. FCN Working Paper No. 11/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May.

Kraas B., Schroedter-Homscheidt M., Pulvermüller B., Madlener R. (2011). Economic Assessment of a Concentrating Solar Power Forecasting System for Participation in the Spanish Electricity Market, FCN Working Paper No. 12/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May.

Stocker A., Großmann A., Madlener R., Wolter M.I., (2011). Sustainable Energy Development in Austria Until 2020: Insights from Applying the Integrated Model "e3.at", FCN Working Paper No. 13/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, July.

Kumbaroğlu G., Madlener R. (2011). Evaluation of Economically Optimal Retrofit Investment Options for Energy Savings in Buildings. FCN Working Paper No. 14/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September.

Bernstein R., Madlener R. (2011). Residential Natural Gas Demand Elasticities in OECD Countries: An ARDL Bounds Testing Approach, FCN Working Paper No. 15/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, October.

Glensk B., Madlener R. (2011). Dynamic Portfolio Selection Methods for Power Generation Assets, FCN Working Paper No. 16/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Michelsen C.C., Madlener R. (2011). Homeowners' Motivation to Adopt a Residential Heating System: A Principal Component Analysis, FCN Working Paper No. 17/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November (revised January 2013).

Razlaf J., Madlener R. (2011). Performance Measurement of CCS Power Plants Using the Capital Asset Pricing Model, FCN Working Paper No. 18/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Himpler S., Madlener R. (2011). Repowering of Wind Turbines: Economics and Optimal Timing, FCN Working Paper No. 19/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November (revised July 2012).

Hackbarth A., Madlener R. (2011). Consumer Preferences for Alternative Fuel Vehicles: A Discrete Choice Analysis, FCN Working Paper No. 20/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December (revised December 2012).

Heuser B., Madlener R. (2011). Geothermal Heat and Power Generation with Binary Plants: A Two-Factor Real Options Analysis, FCN Working Paper No. 21/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Rohlfs W., Madlener R. (2011). Multi-Commodity Real Options Analysis of Power Plant Investments: Discounting Endogenous Risk Structures, FCN Working Paper No. 22/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December (revised July 2012).

2010

Lang J., Madlener R. (2010). Relevance of Risk Capital and Margining for the Valuation of Power Plants: Cash Requirements for Credit Risk Mitigation, FCN Working Paper No. 1/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February.

Michelsen C.C., Madlener R. (2010). Integrated Theoretical Framework for a Homeowner's Decision in Favor of an Innovative Residential Heating System, FCN Working Paper No. 2/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February.

Harmsen - van Hout M.J.W., Herings P.J.-J., Dellaert B.G.C. (2010). The Structure of Online Consumer Communication Networks, FCN Working Paper No. 3/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, March.

Madlener R., Neustadt I. (2010). Renewable Energy Policy in the Presence of Innovation: Does Government Pre-Commitment Matter?, FCN Working Paper No. 4/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, April (revised June 2010 and December 2011).

Harmsen - van Hout M.J.W., Dellaert B.G.C., Herings, P.J.-J. (2010). Behavioral Effects in Individual Decisions of Network Formation: Complexity Reduces Payoff Orientation and Social Preferences, FCN Working Paper No. 5/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May.

Lohwasser R., Madlener R. (2010). Relating R&D and Investment Policies to CCS Market Diffusion Through Two-Factor Learning, FCN Working Paper No. 6/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, June.

Rohlfs W., Madlener R. (2010). Valuation of CCS-Ready Coal-Fired Power Plants: A Multi-Dimensional Real Options Approach, FCN Working Paper No. 7/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, July.

Rohlfs W., Madlener R. (2010). Cost Effectiveness of Carbon Capture-Ready Coal Power Plants with Delayed Retrofit, FCN Working Paper No. 8/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August (revised December 2010).

Gampert M., Madlener R. (2010). Pan-European Management of Electricity Portfolios: Risks and Opportunities of Contract Bundling, FCN Working Paper No. 9/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Glensk B., Madlener R. (2010). Fuzzy Portfolio Optimization for Power Generation Assets, FCN Working Paper No. 10/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Lang J., Madlener R. (2010). Portfolio Optimization for Power Plants: The Impact of Credit Risk Mitigation and Margining, FCN Working Paper No. 11/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September.

Westner G., Madlener R. (2010). Investment in New Power Generation Under Uncertainty: Benefits of CHP vs. Condensing Plants in a Copula-Based Analysis, FCN Working Paper No. 12/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September.

Bellmann E., Lang J., Madlener R. (2010). Cost Evaluation of Credit Risk Securitization in the Electricity Industry: Credit Default Acceptance vs. Margining Costs, FCN Working Paper No. 13/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September (revised May 2011).

Ernst C.-S., Lunz B., Hackbarth A., Madlener R., Sauer D.-U., Eckstein L. (2010). Optimal Battery Size for Serial Plug-in Hybrid Vehicles: A Model-Based Economic Analysis for Germany, FCN Working Paper No. 14/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, October (revised June 2011).

Harmsen - van Hout M.J.W., Herings P.J.-J., Dellaert B.G.C. (2010). Communication Network Formation with Link Specificity and Value Transferability, FCN Working Paper No. 15/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Paulun T., Feess E., Madlener R. (2010). Why Higher Price Sensitivity of Consumers May Increase Average Prices: An Analysis of the European Electricity Market, FCN Working Paper No. 16/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Madlener R., Glensk B. (2010). Portfolio Impact of New Power Generation Investments of E.ON in Germany, Sweden and the UK, FCN Working Paper No. 17/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Ghosh G., Kwasnica A., Shortle J. (2010). A Laboratory Experiment to Compare Two Market Institutions for Emissions Trading, FCN Working Paper No. 18/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Bernstein R., Madlener R. (2010). Short- and Long-Run Electricity Demand Elasticities at the Subsectoral Level: A Cointegration Analysis for German Manufacturing Industries, FCN Working Paper No. 19/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Mazur C., Madlener R. (2010). Impact of Plug-in Hybrid Electric Vehicles and Charging Regimes on Power Generation Costs and Emissions in Germany, FCN Working Paper No. 20/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Madlener R., Stoverink S. (2010). Power Plant Investments in the Turkish Electricity Sector: A Real Options Approach Taking into Account Market Liberalization, FCN Working Paper No. 21/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December (revised July 2011).

Melchior T., Madlener R. (2010). Economic Evaluation of IGCC Plants with Hot Gas Cleaning, FCN Working Paper No. 22/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Lüschen A., Madlener R. (2010). Economics of Biomass Co-Firing in New Hard Coal Power Plants in Germany, FCN Working Paper No. 23/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December (revised July 2012).

Madlener R., Tomm V. (2010). Electricity Consumption of an Ageing Society: Empirical Evidence from a Swiss Household Survey, FCN Working Paper No. 24/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Tomm V., Madlener R. (2010). Appliance Endowment and User Behaviour by Age Group: Insights from a Swiss Micro-Survey on Residential Electricity Demand, FCN Working Paper No. 25/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

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2009

Madlener R., Mathar T. (2009). Development Trends and Economics of Concentrating Solar Power Generation Technologies: A Comparative Analysis, FCN Working Paper No. 1/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November (revised September 2010).

Madlener R., Latz J. (2009). Centralized and Integrated Decentralized Compressed Air Energy Storage for Enhanced Grid Integration of Wind Power, FCN Working Paper No. 2/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November (revised September 2010).

Kraemer C., Madlener R. (2009). Using Fuzzy Real Options Valuation for Assessing Investments in NGCC and CCS Energy Conversion Technology, FCN Working Paper No. 3/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Westner G., Madlener R. (2009). Development of Cogeneration in Germany: A Dynamic Portfolio Analysis Based on the New Regulatory Framework, FCN Working Paper No. 4/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November (revised March 2010).

Westner G., Madlener R. (2009). The Benefit of Regional Diversification of Cogeneration Investments in Europe: A Mean-Variance Portfolio Analysis, FCN Working Paper No. 5/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November (revised March 2010).

Lohwasser R., Madlener R. (2009). Simulation of the European Electricity Market and CCS Development with the HECTOR Model, FCN Working Paper No. 6/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Lohwasser R., Madlener R. (2009). Impact of CCS on the Economics of Coal-Fired Power Plants – Why Investment Costs Do and Efficiency Doesn't Matter, FCN Working Paper No. 7/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Holtermann T., Madlener R. (2009). Assessment of the Technological Development and Economic Potential of Photobioreactors, FCN Working Paper No. 8/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Ghosh G., Carriazo F. (2009). A Comparison of Three Methods of Estimation in the Context of Spatial Modeling, FCN Working Paper No. 9/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Ghosh G., Shortle J. (2009). Water Quality Trading when Nonpoint Pollution Loads are Stochastic, FCN Working Paper No. 10/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Ghosh G., Ribaudo M., Shortle J. (2009). Do Baseline Requirements hinder Trades in Water Quality Trading Programs?, FCN Working Paper No. 11/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Madlener R., Glensk B., Raymond P. (2009). Investigation of E.ON's Power Generation Assets by Using Mean-Variance Portfolio Analysis, FCN Working Paper No. 12/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

2008

Madlener R., Neustadt I., Zweifel P. (2008). Promoting Renewable Electricity Generation in Imperfect Markets: Price vs. Quantity Policies, FCN Working Paper No. 1/2008, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, July (revised November 2011).

Madlener R., Wenk C. (2008). Efficient Investment Portfolios for the Swiss Electricity Supply Sector, FCN Working Paper No. 2/2008, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Omann I., Kowalski K., Bohunovsky L., Madlener R., Stagl S. (2008). The Influence of Social Preferences on Multi-Criteria Evaluation of Energy Scenarios, FCN Working Paper No. 3/2008, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Bernstein R., Madlener R. (2008). The Impact of Disaggregated ICT Capital on Electricity Intensity of Production: Econometric Analysis of Major European Industries, FCN Working Paper No. 4/2008, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September.

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