E.ON Energy Research Center
FCN | Institute for Future Energy Consumer Needs and Behavior

FCN Working Paper No. 17/2011

Homeowners' Motivation to Adopt a Residential Heating System: A Principal Component Analysis

Carl Christian Michelsen and Reinhard Madlener

November 2011
Revised January 2013

Institute for Future Energy Consumer Needs and Behavior (FCN)

School of Business and Economics / E.ON ERC

RWTH AACHEN UNIVERSITY

FCN Working Paper No. 17/2011

Homeowners' Motivation to Adopt a Residential Heating System: A Principal Component Analysis

November 2011
Revised January 2013

Authors' addresses:

Carl Christian Michelsen, Reinhard Madlener
Institute for Future Energy Consumer Needs and Behavior (FCN)
School of Business and Economics / E.ON Energy Research Center
RWTH Aachen University
Mathieustrasse 10
52074 Aachen, Germany
E-mail: CMichelsen@eonerc.rwth-aachen.de, RMadlener@eonerc.rwth-aachen.de

Publisher: Prof. Dr. Reinhard Madlener
Chair of Energy Economics and Management
Director, Institute for Future Energy Consumer Needs and Behavior (FCN)
E.ON Energy Research Center (E.ON ERC)
RWTH Aachen University
Mathieustrasse 10, 52074 Aachen, Germany
Phone: +49 (0) 241-80 49820
Fax: +49 (0) 241-80 49829
Web: www.eonerc.rwth-aachen.de/fcn
E-mail: post_fcn@eonerc.rwth-aachen.de

Homeowners' Motivation to Adopt a Residential Heating System: A Principal Component Analysis

Carl Christian Michelsen* and Reinhard Madlener

*Institute for Future Energy Consumer Needs and Behavior (FCN), School of Business and Economics / E.ON Energy Research Center, RWTH Aachen University, Mathieustr. 10, 52074 Aachen, Germany; * Corresponding author (C.C. Michelsen), Phone: +49 241 80 49 836, Fax: +49 241 80 49 829, E-mail address: CMichelsen@eonerc.rwth-aachen.de*

November 2011, Revised January 2013

Abstract

Heating demand accounts for a large fraction of the overall energy demand of private households in Germany. A better understanding of the adoption and diffusion of energy-efficient and renewables-based residential heating systems (RHS) is of high policy relevance, particularly against the background of climate change, security of energy supply and increasing energy prices. In this paper, we explore the multi-dimensionality of the homeowners' motivation to decide between competing RHS. A questionnaire survey (N=2440) conducted in 2010 among homeowners who had recently installed a RHS provides the empirical foundation. Principal component analysis shows that 25 items capturing different adoption motivations can be grouped around six dimensions: (1) cost aspects, (2) general attitude towards the RHS, (3) government grant, (4) reactions to external threats (i.e. environmental or energy supply security considerations), (5) comfort considerations, and (6) influence of peers. Moreover, a cluster analysis with the identified motivational factors as segmentation variables reveals three adopter types: (1) the convenience-oriented, (2) the consequences-aware, and (3) the multilaterally-motivated RHS adopter. Finally, we show that the influence of the motivational factors on the adoption decision also differs by certain characteristics of the homeowner and features of the home.

Key words: Residential heating systems; technology adoption motivation; consumer behavior

JEL Classification Nos.: D12, O33, Q41, Q42, R22

1 Introduction

Heating demand accounts for a large fraction of the overall residential energy demand. For example, private households in Germany consumed about 1884 PJ for heating in 2006. This amounts to more than 73% of the total final energy demand for residential purposes (Mayer and Flachmann, 2008). In Germany, residential heat supply is mainly based on two fossil fuels, heating oil and natural gas. According to BDEW (2009), in 2008 about 48.5% of the existing homes were using gas for heating, while about 30% had an oil-based RHS. Moreover, 60% of the newly built homes were equipped with a gas-fired RHS (BDEW, 2009). Due to this important role of oil and gas, residential heating is strongly linked to policy considerations related to global warming, the security of energy supply, and increasing energy prices.

In order to deal with these energy policy challenges, the German government has set the goal of raising the share of renewable energies in residential heat supply from 6% to 14% by 2020 (EEWärmeG, 2008). A number of policy measures targeting residential heating demand have been implemented for achieving this goal. These measures target the insulation of the building shell as well as the conversion efficiency of residential heating systems (RHS) in newly built and existing residential buildings. Regulatory frameworks, such as the "Act on the Promotion of Renewable Energies in the Heat Sector (EEWärmeG)" or the "Energy Saving Ordinance (ENEV)", oblige owners of newly built single- or two-family homes to choose a RHS which is (partly) based on renewable energy sources. For owners of existing homes subject to a major renovation the situation is somewhat different. In most federal states, there are no obligations to use renewable energies for residential heating, except for the federal state of Baden-Württemberg (mandatory 10% share of renewable energies).

As a result, homeowners today can choose among a number of different competing RHS (partly) based on renewable energies. These systems also include the gas- or oil-fired condensing boiler in combination with a solar thermal collector, the electric heat pump and the wood pellet-fired boiler, three fairly innovative RHS. All four of these provide the same output in the form of thermal heat. However, there are significant differences in their characteristics. Currently, it is not clear which of the competing renewables-based RHS will gain the highest market share under the given framework conditions. Therefore, studying the underlying determinants of the homeowners' adoption decisions with respect to a specific innovative RHS out of a set of alternative systems can contribute to a better understanding of the RHS market. Besides *contextual elements*, such as socio-demographic, spatial or home characteristics, *motivational elements* on the personal-sphere level seem to play a certain role in the process of adopting a specific RHS. These elements also represent different channels for policy interventions targeting RHS.

Economic research on the adoption and diffusion of sustainable energy technologies has often disregarded the impact of personal-sphere elements beyond that of a rational actor with perfect or limited information. The traditional economic perspective sees cost-benefit considerations and utility maximization as the main determinants of an individual's energy technology adoption decision (e.g. Faiers et al., 2007). However, the adoption of sustainable energy systems can be seen as personal- or private-sphere behavior and, therefore, besides economic considerations, includes behavioral elements as well (e.g. Stern, 2005).

In this paper, we argue that the motivational aspects to decide between competing RHS cluster around different latent dimensions underlying the decision-making process.[1] Therefore, the following questions guide our research: What are the components that constitute the homeowners' motivation to decide between competing RHS? Are there any differences in the RHS adoption motivation across groups of homeowners segmented according to selected socio-demographic characteristics or features of their home? What characterizes clusters of homeowners segmented according to their RHS adoption motivation?

For the purpose of our research, we carried out a representative, self-administered national survey among randomly selected owners of existing or newly built 1- and 2-family homes in Germany. The participants were sourced from a list of homeowners that had received a financial grant by the German Federal Office of Economics and Export Control (BAFA – *Bundesamt für Wirtschaft und Ausfuhrkontrolle*) between January 2009 and August 2010 for installing a new RHS that is (at least partly) based on renewable energy sources. Hereby, we gathered a unique set of micro data on motivational aspects of actual RHS adoption decisions. Our research is restricted to the four most frequently adopted types of RHS in Germany: oil- or gas-fired condensing boiler with solar thermal support, heat pump, and wood pellet-fired boiler. We investigated the data on the homeowners' RHS adoption motivations by means of

[1] This research does not address the issue of what motivates homeowners to invest in a new RHS. Rather, we explore motivational factors that determine the decision between different types of RHS. Since we investigate real (i.e. not hypothetical) adoption decisions that were taken recently, we focus on the latent dimensions and their meanings that supported (i.e. motivated) the RHS adoption decision. Therefore, possible barriers towards adopting a certain RHS are not addressed in our research.

an explorative research approach (combined principal component analysis and cluster analysis).[2]

To our knowledge, little research has been done so far to empirically examine the dimensionality of the homeowners' RHS adoption decisions by means of data on real decisions (e.g. Decker, 2010; Sopha and Klöckner, 2011). Typically, research in this field uses stated preference data on hypothetical RHS adoption decisions that stem from choice experiments (e.g. Scarpa and Willis, 2010; Claudy et al., 2011; Rouvinen and Matero, 2012). Therefore, we make a significant empirical contribution towards a better understanding of the RHS adoption motivation at the level of the individual homeowner. Furthermore, a more detailed knowledge of the underlying dimensions behind the RHS adoption motivation can also contribute to a better design of policy instruments targeting RHS and marketing strategies by RHS manufacturers. Insights from this research for the German case can at least qualitatively also be transferred to other countries aiming at reducing residential CO_2 emissions.

The paper proceeds as follows: Section 2 reviews relevant theories and models on individual behavior and decision-making as well as empirical studies on the RHS adoption motivation. Section 3 outlines the research design, providing a brief overview of the survey instrument and the analytical procedure. In section 4, we present the results from our analysis. In the final section 5, we discuss the findings and provide implications for policy making and business, and conclude with some comments on contributions and limitations of this study and suggestions for future research.

2 Individual decision-making and the motivation to adopt a technology

2.1 Theoretical approaches towards technology adoption and diffusion

A considerable amount of research on technology adoption and consumer behavior is based on cognitive and normative behavioral models as well as approaches that look at the adoption and diffusion of innovations as a social process (see Madlener and Harmsen – van Hout, 2011, for a useful survey on the energy consumer behavior literature).

Cognitive models and theories have their roots in the research around attitude formation and social psychology. In particular, this approach is often applied in studies on the adoption of

[2] In parallel research, we empirically investigate a theoretically grounded framework on the homeowners' decision in favor of an innovative RHS by means of a confirmatory research approach (Michelsen and Madlener, paper in preparation).

environmentally friendly products or health-related behavior. Two well-known examples for cognitive models include Ajzen and Fishbein's (1980) theory of reasoned action (TRA) and Ajzen's (1991) theory of planned behavior (TPB). Both theories assume that behavior is rationally driven and that there is a linear relationship between beliefs and behavior. In particular, *behavioral intention* determines actual behavior and serves as a proximal measure of behavior. In both models, behavioral intention depends on an individual's *attitude* towards performing the behavior, and *subjective norms* (i.e. the influence of peers). However, behavior is not always under an individual's full control. In order to predict behavior more accurately, the TPB also includes the component *perceived behavioral control* in order to capture non-motivational factors, such as the availability of resources, the ability to carry out a certain action, or environmental constraints. Normative decision models for pro-environmental behavior, in contrast, focus on the role of values and moral norms. Examples include Schwartz's (1977) norm activation theory (NAT), Dunlap and Van Liere's (1978) new environmental paradigm (NEP) or Stern's (1999) value-belief-norm (VBN) theory. Similar to cognitive theories, these models are theoretical frameworks for attitude-related research from a psychological view. However, they do not account for external conditions, such as economic factors or regulatory constraints. In order to deal with the effect of contextual factors, Stern (2000) proposes the attitude-behavior-context (ABC) model. According to this approach, individuals with differences in their attitudes and beliefs can have a different understanding of certain contextual factors.

Cognitive and normative approaches assume a linear and rational relationship between the adopter's perceptions and the actual adoption behavior. This is a rather limited perspective for understanding the RHS adoption motivation. Other aspects beyond cognitive assessment and rational choice, including emotional influences or socio-cultural features, also seem to be relevant for the adoption decision (see e.g. Faiers et al., 2007). The leading model that sees the adoption and diffusion of innovations as a social process is Rogers' (2003) diffusion of innovations (DoI) model. This model describes the adoption and diffusion of innovations as a social communication process of five sequential stages. Moreover, Rogers (2003) was one of the first researchers to present a concept for systematically characterizing innovations (perceived attributes of innovations). He introduces five different attributes in order to describe the attitude formation towards an innovation in more detail. These attributes include *relative advantage* (comparison of attributes), *compatibility* (correspondence to habits, norms or needs), *complexity* (effort related to understanding or usage), *observability* (visibility of the adoption to others) and *trialability* (possibility to test before adoption). Based on Rogers' attributes of innovations, there have been attempts to develop this approach further. The technology acceptance model (TAM) by Davis et al. (1989) aims at simplifying and reducing the number of characteristics. The approach consists of only two explanatory variables, including *perceived usefulness* (enhancement of possibilities) and *perceived ease of use* (effort related to the use). In contrast, the perceived characteristics of innovations (PCI) scale by Moore and Benbasat (1991) aims at developing a comprehensive and unified measure. They add two new characteristics to Rogers' attributes of innovations, including *voluntariness* (adoption is of free will) and *image* (improved image due to the adoption). Moreover, Moore and Benbasat (1991) split Rogers' attribute "observability" in *result demonstrability* (degree to which results of usage are directly observable) and *visibility* (usage is visible to others).

The perceived attributes of innovations, TAM and PCI scale are important concepts that are often applied in technology adoption research for describing properties of innovations in a systematic manner or for analyzing drivers and barriers in the adoption process. These models can be used for operationalizing the constructs of more general theories, such as the TPB. For the case of RHS, we hypothesize that the adopters' attitudes towards a RHS (i.e. personal opinion or perceptions about the RHS) can be operationalized by perceptions about (1) the *relative advantage* (i.e. comparison of certain technical or economic attributes of a RHS to those of alternative RHS), (2) *perceived ease of use* (i.e. effort linked to the operation of the RHS, such as maintenance requirements or fuel acquisition), *trialability* (i.e. existing knowledge or prior experience linked to the RHS), (3) *result demonstrability* (i.e. degree of difficulty linked to understanding and explaining the RHS), and (4) *compatibility with existing habits and norms* (i.e. degree of required substantial changes in daily routines, needs, behavior or norms due to the RHS adoption). The influence of subjective norms (i.e. the influence of significant others, such as family or friends) can be operationalized by perceptions about the (1) *visibility* (i.e. usage of the RHS visible to significant others, such as neighbors or friends) and (2) *image* (i.e. positive response or recognition by others due to the adoption of the RHS). Finally, the dimension that captures perceived behavioral control (i.e. the influence of external constraints, such as the belief about how characteristics of the home or financial possibilities constrain the RHS adoption) can be operationalized by perceptions about the (1) *compatibility with infrastructure* (i.e. characteristics of the home or financial possibilities influence the RHS adoption) and (2) *voluntariness* (i.e. regulatory constraints impact the adoption of the RHS). In the following, we use this as a framework for categorizing the findings from the review of the empirical literature on RHS adoption motivation.

2.2 Empirical studies on RHS adoption by private homeowners

Empirical studies on the adoption of RHS by private homeowners can be divided into such that draw on (i) revealed preference (i.e. ownership data mostly from large household surveys on the national level) or data on real adoption decisions, and (ii) stated preference data on hypothetical adoption decisions (i.e. data from choice experiments or surveys designed for the specific research question). In the following, we focus the review on variables capturing behavioral aspects of the RHS adoption motivation.

The first strand of empirical research mainly focuses on household-specific data, such as socio-demographic, home or geographical characteristics linked to the ownership (application) of a RHS by means of choice modeling (e.g. Dubin and McFadden, 1984; Vaage, 2000; Mills and Schleich, 2009; Braun, 2010; Goto et al., 2011). Typically, such studies do not address behavioral elements of the RHS adoption motivation. In contrast, empirical research on real adoption decisions that applies theoretical frameworks including Rogers' diffusion of innovations theory, Rogers' perceived attributes of innovations or similar approaches has a clear focus on behavioral aspects of the RHS adoption motivation (e.g. Decker, 2010; Decker et al., 2010; Madlener and Artho, 2005; Mahapatra and Gustavsson, 2007, 2008, 2009; Michelsen and Madlener, 2012; Sopha and Klöckner, 2011). Decker (2010) and Decker et al. (2010) find for the case of Germany that costs, environmental aspects, required fuel, comfort considerations, aspects related to the delivery of the fuel, information about the system and public subsidies all influence the adoption motivation. Madlener and Artho (2005) investigate barriers to the adoption of wood chip-fired boilers among residential building cooperatives in Switzerland. The findings of the study show that compatibility, social norms and relative advantage (e.g. RHS-related costs, space requirements, environmental considerations, effort related to fuel acquisition, energy supply security, ease of use) impact the adoption motivation. The studies of Mahapatra and Gustavsson (2007, 2008, 2009) on the adoption of residential heating systems in Sweden use attributes, such as annual costs of heating, investment costs, functional reliability, indoor air quality, security of fuel supply, system automation, environmentally benign system, increased market value of the home, low GHG emissions, and time required to gather information. Costs and reliability of the system are found to have the most important effects. Michelsen and Madlener (2012) investigate, besides socio-demographic, home and spatial variables, the influence of preferences regarding RHS-specific attributes on the adoption motivation for the case of Germany. They find that energy savings, independence from fossil fuels, environmental concerns and considerations related to comfort motivate homeowners to adopt a new innovative RHS. Tapaninen (2008) and Tapaninen et al. (2009a, b) study the case of wood pellet-fired RHS in Finland. A main finding is that relative advantage is the most relevant attribute for the RHS adoption motivation. Further similar studies with comparable findings include Nyrud et al. (2008) on wood stoves in Norway, Lillemo et al. (2011) on heating system investments in Norway, and Woersdorfer and Kaus (2011) on solar thermal systems in Germany.

The second strand of research primarily targets preferences related to certain attributes of RHS in hypothetical adoption decisions (e.g. Scarpa and Willis, 2010; Claudy et al., 2011; Rouvinen and Matero, 2012). The primary objective of research based on choice experiments is to investigate the willingness to pay (WTP) for selected RHS. For this purpose, the relevance of selected system attributes (e.g. investment, operating and energy costs), energy supply security (e.g. fuel price stability), environmental considerations (e.g. CO_2 emissions) or comfort (e.g. required work or effort related to the RHS) for the (hypothetical) choice of a RHS is investigated. For example, Claudy et al. (2011) analyze the influence of perceived product characteristics on homeowners' WTP for micro-generation technologies in Ireland. They find that the WTP is influenced by the homeowners' perception of product characteristics, normative influences, and socio-demographic characteristics. Furthermore, Scarpa and Willis (2010) study the WTP of British households for micro-generation technologies (including, among others, solar thermal collectors, heat pumps, biomass boilers and micro-cogeneration). They analyze the influence of the attributes investment costs, energy costs, maintenance costs, inconvenience of the system, and recommendation by someone else. A study with similar findings is Rouvinen and Matero (2012) on the role of RHS-specific attributes in the choice of a particular RHS by private homeowners in Finland.

Based on our review of the theoretical literature (cf. section 2.1), we divide the motivational constructs identified from the empirical studies into factors that have the character of rational decision-making (e.g. economic aspects, such as RHS-related costs or the availability of a capital grant) as well as factors of an emotional (i.e. cognitive or psychological) nature on the individual (e.g. aspects related to RHS-specific attributes such as energy supply security, environmental considerations, comfort, and the general attitude and perceptions linked to the RHS) and social level (e.g. influence of peers or social norms). Table 1 assigns the motivational factors identified from the empirical literature on RHS adoption to six main categories. In the remainder of this paper, we use the insights from the literature review for empirically investigating the homeowners' RHS adoption motivation for the case of Germany. However, there might be additional motivational aspects that we have not derived from the literature review or practical considerations. For example, a qualitative study based on in-depth interviews with homeowners may have revealed more aspects of the RHS adoption motivation. Therefore, the set of items underlying this study may not be exhaustive.

Table 1: Summary and categorization of motivational factors identified from the empirical literature on RHS adoption

Category	**Motivational factors**
Economic aspects	Investment costs[d, e, i, k, l, o, p] / annual costs of heating[b, c, e, f, g, h, i, k, m, o, p] / fuel price[b, c, i, j, o, p] / maintenance costs[b, c, i, j, k, l, o, p] / payback period[b, c, e, o, p] / capital grant[b, c, i, j, o, p] / market value of the home[d, f, g, h]
Environmental considerations	Ecological reasons[a, b, c, d, e, f, g, h, i, j, q, o, p] / climate protection[b, c, d, f, g, h, k, q] / particulate emissions[b, c, e, k] / energy efficiency and savings[d, i, j, l, o, p] / indoor air quality[b, c, d, f, g, h, m] / health aspects[b, c]
Energy supply security	Independence from fossil fuels[a, b, c, i] / security of fuel supply[b, c, e, f, g, h, i, m] / fuel from regional and renewable energy sources[b, c, e, o, p]
Comfort considerations	Home comfort[i, j, o, p] / utility value of the home[o, p] / required effort [b, c, d, k, m] / ease of use [b, c, o, p] / system automation[f, g, h, o, p] / maintenance requirements [b, c, i, k, o, p] / fuel acquisition [b, c, i, k, o, p] / durability[b, c] / functional reliability [b, c, e, f, g, h, j, m, o, p] / perceived risks[a, e, o, p]
General attitude	Compatibility with daily habits or routines[a, e, m] / perceived controllability[a, b, c, e, o, p] / perceived familiarity with the system [b, c, j, n, o, p]
Social reasons	Peer group behavior[a, e, i, j, l, m, q] / image of the RHS[a, b, c, e, i, j] / professional advice[b, c, l] / availability of specialized installer for the RHS[b,c]

Sources: **[a]** Claudy et al., 2011; **[b]** Decker, 2010; **[c]** Decker et al., 2010; **[d]** Lillemo et al. (2011); **[e]** Madlener and Artho, 2005; **[f, g, h]** Mahapatra and Gustavsson, 2007, 2008, 2009; **[i]** Michelsen and Madlener, 2012; **[j]** Nyrud et al. (2008); **[k]** Rouvinen and Matero, 2012; **[l]** Scarpa and Willis, 2010; **[m]** Sopha and Klöckner, 2011; **[n]** Tapaninen (2008); **[o, p]** Tapaninen et al. (2009a, b); **[q]** Woersdorfer and Kaus (2011)

3 Methodology

3.1 Questionnaire development and implementation

In order to collect data on the homeowners' adoption decisions, we constructed and implemented a self-administered questionnaire for a national survey in Germany. The questionnaire included questions on socio-demographic, home and spatial (i.e. geographical location) characteristics of the homeowners. Moreover, we included questions based on the motivational variables identified from the theoretical and empirical literature (cf. section 2). The wording of the items was taken from previous surveys on technology adoption motivation and adjusted to the case of RHS in Germany. We measured the items on a 5-point Likert scale (1 = "completely disagree" – 5 = "completely agree" or 1 = "unimportant" – 5 = "very important"). When designing the questionnaire, we tried to minimize a possible common method bias. This included a cover letter stating that there are no "right" or "wrong" answers, that the participants should give true answers and that they remain anonymous. Finally, the information on the explanatory variable (i.e. adopted RHS) was provided by BAFA and not of those that participated in the survey. Therefore, we expect the common method bias to be minimized.

We mailed the questionnaires to 5000 randomly selected homeowners who had received a grant by BAFA for installing a new RHS between January 2009 and August 2010. The participants were owners of a newly built or existing home that adopted either a gas-fired condensing boiler with solar thermal support (GAS-ST), an oil-fired condensing boiler with solar thermal support (OIL-ST), an electric heat pump (HEAT-P), or a wood pellet-fired boiler (WOOD). We were able to raise the overall response rate to 59.7% (*N*=2985) by several measures including a reminder letter, a replacement questionnaire, and a small give away.[3] A more detailed description of the development and implementation of the questionnaire can be found in Michelsen and Madlener (2012). For the purpose of our analysis, we excluded 302 cases where either the owner does not live in the home, the home is a multi-family home (i.e. not a 1- or 2-family home), or where the main RHS is not GAS-ST, OIL-ST, HEAT-P or WOOD (*N*=2683). Moreover, we excluded 67 completely or almost empty questionnaires (*N*=2616). Finally, we excluded 176 cases where at least one of the variables for the PCA is missing (casewise deletion). Therefore, the net sample for our analysis consisted of *N*=2440 observations.

Michelsen and Madlener (2012) discuss possible limitations and biases related to the organization of the questionnaire. This includes that the survey only covers RHS adopters that received a BAFA capital grant (according to Langniß et al. (2010) about 74% of the eligible RHS installations received a BAFA grant in 2009), changing framework conditions for the grant recipients in the period of time considered or that the focus of the study is on selected RHS only (however, the most frequently adopted RHS including GAS-ST, OIL-ST, HEAT-P and WOOD). Moreover, there are limitations with regard to the scales of measurement of certain variables (e.g. *Income* or *Size* are categorical variables). Finally, there are differences between the regional distributions of homes in our dataset compared to the total number of homes in Germany. Therefore, the representativeness of our dataset is restricted to BAFA

[3] The give-away was a thermometer card (*Energiesparkarte*) indicating the actual room temperature, the appropriate temperature level for different types of rooms and possibilities for energy savings related to residential heating. Moreover, it stated that reducing the indoor temperature by 1°C results in energy savings of about 6%, and provided some reference to the institute conducting the survey.

grant recipients that own a 1- or 2-family home and that have purchased a new RHS (partly) based on renewable energies.

3.2 Analytical procedure

Our research strategy, in which we apply principal component analysis (PCA) and cluster analysis (CA), is a commonly used approach for exploring survey data (see e.g. Axsen et al., 2012, on the adoption of pro-environmental technologies; Barr et al., 2005, on the household energy gap; Gilg and Barr, 2006, on behavioral attitudes towards water saving; Guiot and Roux, 2010, on second-hand shoppers' motivation; Rijnsoever et al., 2009, on consumer car preferences; and Sütterlin et al., 2011, on energy-related behavioral characteristics). The investigation of the dimensionality of survey data by means of PCA (i.e. conversion of a set of observations of possibly correlated variables into uncorrelated components) and CA (i.e. assigning a set of objects into groups) requires decisions by the researcher regarding the analytical procedure. These decisions impact the outcome of the analysis. In the following, we briefly outline the applied analytical procedure.

We applied PCA on 25 variables capturing different motivational constructs of the RHS adoption in order to summarize the information in the original data. We selected the variables based on the main categories of motivational factors identified from the literature review (cf. section 2). An overview of the wording and the summary statistics of the included variables can be found in table 2. In order to determine the number of components to be extracted, we compared the results of different factor retention criteria. For this purpose, we applied criteria that are based on the researcher's subjective assessment (i.e. rules of thumb), such as *Kaiser criterion* (*eigenvalues-greater-than-one rule*) or the *scree plot* as well as statistically based methods that deliver objective evidence, such as *Horn's parallel analysis (PA)* or *Velicer's minimum average partial (MAP) test*. According to O'Connor (2000) the statistically based factor retention methods *PA* and *MAP test* should be preferred to rules of thumb such as the Kaiser criterion or scree plot. Further, the decision on the number of factors to be extracted should be based on a comparison of different procedures. The Kaiser criterion suggested extracting seven components, whereas the results of the original MAP test and PA indicated six components.[4] The solution with six components had no items that load high on multiple components and the number of items for each component is at least three. Moreover, we

[4] The revised MAP test suggests extracting four components. However, the smallest average 4th power partial correlations (r^4) are very similar for the 4th, 5th and 6th component. Therefore, we follow the results of the original MAP test as it shows a clearer picture. For a summary of the test results, the reader is referred to the appendix.

found the reliability (i.e. Cronbach's alpha) of the components higher than 0.6 (which is acceptable for exploratory research) and in a similar range.[5] An investigation of the scree plot also supports the decision to extract six components. As rotation method, we applied promax rotation since we expected to find components that can be attributed to more general components. Moreover, table A-2 in the appendix confirms our expectations and shows that most of the component combinations are weakly (i.e. $0.1 > r < 0.3$) or moderately (i.e. $0.3 > r < 0.5$) correlated (see Cohen, 1988, for a discussion on the strength of relationships between variables).

Based on the estimated factor scores of the identified components from the PCA as segmentation variables, we carried out a hierarchical CA. We decided to apply a hierarchical approach since the character of our analysis is explorative (i.e. we assume that there is no previous knowledge about the possible number of clusters). Due to the metric character of the factor scores (i.e. interval-scaled data), we used the squared Euclidean distance as a proximity measure for analyzing differences and matches between the cases. The squared Euclidean distance puts a progressively greater weight on objects that are farther apart. As a clustering algorithm, we applied Ward's method. This clustering method is widely used by researchers and regarded as the most powerful method for metric data (see e.g. Bergs, 1981, pp.96). However, Ward's method is sensitive to distortions in the data caused by outliers. Therefore, we carried out a single leakage cluster analysis in a preceding step. Based on this, we identified and excluded 93 outliers. Thus, the total number of observations used for the CA applying Ward's method was N=2347. We determined the optimal cluster solution based on two statistically-based stopping rules, including the Caliński-Harabasz pseudo-F index and the Duda-Hart Je(2)/Je(1) index. Milligan and Cooper (1985) showed in an evaluation of 30 stopping rules that these two rules are among the best. In our analysis, the Caliński-Harbasz index suggested a two-cluster solution while the Duda-Hart index a three-cluster solution. In both cluster solutions, we found meaningful and significant differences across all six segmentation variables. The third cluster in the three-cluster solution differed significantly in several segmentation variables from the clusters in the two-cluster solution. This provides further interesting insights into the different types of RHS adopters. Therefore, we opted for the three-cluster solution. An exploration of different proximity measures and algorithms for

[5] In general, a scale is seen as reliable if we find a Cronbach's alpha higher than 0.7 (i.e. scale explains more than 50% of the variance). For established scales, the Cronbach's alpha should be above 0.8. On the other hand, in exploratory research (i.e. involving the development and use of new scales) a minimum alpha of 0.6 is also considered acceptable (see e.g. Nunnally, 1978).

hierarchical CA showed that applying Ward's method with the squared Euclidean distance as a proximity measure delivers the most distinct cluster solution.

4 Results

4.1 Characterizing the RHS adoption motivation

The PCA groups the 25 variables around six components: (1) cost aspects, (2) general attitude towards the RHS, (3) the capital grant provided by the government, (4) reactions to external threats, (5) comfort considerations, and (6) the influence of peers. The KMO statistic is at .792, which shows that the PCA is suitable for the initial set of variables (i.e. the model explains a major part of the variance). Moreover, the Bartlett test is highly significant (< .001), i.e. we can reject the hypothesis that all items are uncorrelated. Table 2 illustrates the results of the PCA.

An overview of the summary statistics of variables that describe selected socio-demographic, home and spatial characteristics of the RHS adopters in our sample can be found in table A-3 in the appendix. These variables were also used for separating the adopters into groups for the ANOVA and *t*-tests.

Table 2: Statistics of the extracted components (*N* = 2440)

No.	Component description	Cronbach's alpha	Item labeling and wording		Mean	S.E.	Loading	MSA	h^2
1	**Cost aspects**	.768	c1_1	How important were the expected total costs for your decision?	2.67	1.298	**.796**	.836	.611
			c1_2	How important was the current fuel price for your decision?	2.99	1.485	**.686**	.819	.557
			c1_3	How important were expectations about the future fuel price for your decision?	3.09	1.514	**.674**	.801	.529
			c1_4	How important were the maintenance costs for your decision?	2.05	1.259	**.673**	.837	.502
			c1_5	How important was the expected payback period for your decision?	2.44	1.390	**.648**	.908	.422
			c1_6	How important were the initial purchase costs for your decision?	3.22	1.222	**.537**	.870	.421
2	**General attitude towards the RHS**	.778	c2_1	I can quickly accustom myself to the RHS.	4.27	.824	**.812**	.799	.648
			c2_2	To me, the advantages outweigh the disadvantages of the RHS.	4.32	.804	**.749**	.823	.556
			c2_3	If necessary, I would have no difficulty telling others about the RHS benefits.	3.78	.920	**.705**	.851	.533
			c2_4	Using the RHS does not result in extra work.	3.78	1.005	**.698**	.833	.549
			c2_5	Overall, I belief that the RHS is easy to use.	3.89	.883	**.673**	.843	.493
3	**Government grant**	.812	c3_1	The BAFA grant made the installation of the RHS possible.	2.03	1.210	**.882**	.809	.750
			c3_2	Without the BAFA grant, I would have chosen another RHS.	1.83	1.096	**.859**	.811	.682
			c3_3	The possibility to receive a BAFA grant supported my decision in favor of the RHS.	3.44	1.296	**.786**	.878	.632
			c3_4	How important were the purchase costs minus BAFA grant for your decision?	2.34	1.436	**.595**	.877	.629
4	**Reactions to external threats**	.697	c4_1	I expected more independence from politically motivated supply crisis of oil and gas.	3.80	1.291	**.892**	.614	.789
			c4_2	My intention was to become more independent from fluctuating energy prices.	3.87	1.113	**.884**	.631	.788
			c4_3	My intention was to contribute to environmental protection.	4.13	.969	**.439**	.873	.273
5	**Comfort considerations**	.683	c5_1	My intention was to have a low effort with fuel acquisition.	3.16	1.281	**.869**	.659	.747
			c5_2	My intention was to have a RHS with little maintenance requirements.	3.23	1.208	**.846**	.656	.739
			c5_3	I expected an improved utility value of my home by the installation of the RHS.	3.12	1.198	**.535**	.837	.356
6	**Influence of peers**	.634	c6_1	Other people have influenced my decision in favor of this RHS.	2.40	1.220	**.801**	.688	.630
			c6_2	The opinion of peers (e.g. friends or family) was important for my decision.	2.40	1.198	**.782**	.732	.609
			c6_3	I knew a number of other people with a similar RHS.	2.20	1.084	**.731**	.759	.527
			c6_4	By installing this RHS, I expected a positive response by others (e.g. recognition).	1.93	1.094	**.357**	.842	.293

Table 3: Statistically significant results from ANOVA, *t*-tests and post-hoc tests for components 1-6

Variable	Component 1	Component 2	Component 3	Component 4	Component 5	Component 6
Adopted RHS	Welch $F(3, 940.94) = 32.40$, ($p < .01$), $\eta^2 = .04$: weak WOOD / GAS-ST: $d = .55$ WOOD / OIL-ST: $d = .24$ WOOD / HEAT-P: $d = .29$ OIL-ST / GAS-ST: $d = .26$ HEAT-P / GAS-ST: $d = .30$	No significant differences	$F(3, 2436) = 43.99$, ($p < .01$), $\eta^2 = .05$: weak WOOD / GAS-ST: $d = .52$ WOOD / OIL-ST: $d = .33$ WOOD / HEAT-P: $d = .56$ OIL-ST / GAS-ST: $d = .20$ OIL-ST / HEAT-P: $d = .23$	Welch $F(3, 917.21) = 337.10$, ($p < .01$), $\eta^2 = .32$: strong GAS-ST / HEAT-P: $d = –1.25$ GAS-ST / WOOD: $d = –1.54$ OIL-ST / HEAT-P: $d = –1.15$ OIL-ST / WOOD: $d = –1.54$ WOOD / HEAT-P: $d = .37$	*F*-test, $F(3, 2436) = 75.05$, ($p < .01$), $\eta^2 = .09$: medium WOOD / GAS-ST: $d = –.60$ WOOD / HEAT-P: $d = –.76$ OIL-ST / GAS-ST: $d = –.23$ OIL-ST / HEAT-P: $d = –.40$ OIL-ST / WOOD: $d = .37$	No significant differences
Type of home	$t(2438) = -8.97$, ($p < .01$, two-sided), $d = .37$: small	No significant differences	$t(2234.73) = –11.34$, ($p < .01$, two-sided), $d = –.46$: small	No significant differences	$t(2438) = 4.74$, ($p < .01$, two-sided), $d = .20$: small	No significant differences
1-family home	*No significant differences*	No significant differences	$t(2429) = –5.59$, ($p < .01$, two-sided), $d = –.26$: small	No significant differences	No significant differences	No significant differences
Size of the home	$F(4, 2422) = 7.36$, ($p < .01$), $\eta^2 = .01$: weak 100-149 m^2 / 150-199 m^2: $d = –.24$ 100-149 m^2 / 200-249 m^2: $d = –.21$	No significant differences	No significant differences	*F*-test, $F(4, 2422) = 4.11$, ($p < .01$), $\eta^2 = .01$: weak 100-149 m^2 / 200-249 m^2: $d = –.22$	No significant differences	No significant differences
Energy standard of the home	$F(4, 2300) = 22.49$, ($p < .01$), $\eta^2 = .04$: weak non-renov. / low energy: $d =. 28$ non-renov. / newly built: $d = .49$ renovated / low energy: $d = .35$	No significant differences	$F(4, 2300) = 23.57$, ($p < .01$), $\eta^2 = .04$: weak non-renov. / newly built: $d =. 41$ non-renov. / low energy: $d = .41$ renovated / newly built: $d = .40$ renovated / low energy: $d = .41$	No significant differences	$F(4, 2300) = 4.84$, ($p < .01$), $\eta^2 = .01$: weak non-renov. / newly built: $d = –.20$ non-renov. / low energy: $d = –.24$	No significant differences
Net monthly income of the household	No significant differences	Welch $F(5, 636.703) = 2.32$, ($p < .05$), $\eta^2 = .01$: weak €3000-3999 / €5000-5999: $d = –.25$	Welch $F(5, 641.167) = 7.44$, ($p < .01$), $\eta^2 = .02$: weak < €2000 / €3000-3999: $d = .28$ < €2000 / €5000-5999: $d = .38$ < €2000 / €6000 >: $d = .52$ €6000 > / €2000-2999: $d = –.38$ €6000 >/ €3000-3999: $d = –.30$ €6000 >/ €4000-4999: $d = –.33$	No significant differences	$F(5, 2228) = 10.50$, ($p < .01$), $\eta^2 = .02$: weak < €2000 / €2000-2999: $d = .23$ < €2000 / €3000-3999: $d = .31$ < €2000 / €4000-4999: $d = .50$ < €2000 / €5000-5999: $d = .48$ < €2000 / €6000 >: $d = .46$ €2000-2999 / €4000-4999: $d = .28$	No significant differences

Notes: We report statistically significant results ($p < .05$) and their practical significance (effect size denotes at least a weak, i.e. $\eta^2 \geq .01$, or small effect, i.e. $d \geq .20$) from the ANOVA and *t*-tests. For the ANOVA, we use the effect size partial η^2. It measures the strength of association between one or several predictors and a dependent variable in the sample. According to Cohen (1988, Ch. 2) a partial η^2 of .01 denotes a weak, .06 a medium, and .14 a strong effect. For the *t*- and post-hoc tests, we apply Cohen's d (*d*). It is a suitable indicator for comparing differences between the means of groups in a sample (i.e. practical significance or distance between the means). According to Cohen (1988, Ch. 2) a d = (+/-) .20 represents a small, (+/-) .50 a moderate and (+/-) .80 a large effect. For the post-hoc tests, we apply either the Hochberg test (homogeneity of variances: *F*-test) or the Games-Howell test (heterogeneity of variances: Welch *F*-test). We report all pairs with statistically significant differences and the corresponding effect size (*d*).

In the following, we briefly describe the extracted components. Moreover, in order to explore differences in the RHS adoption motivation between groups of adopters segmented according to socio-demographic and home characteristics, we discuss statistically significant ANOVA and *t*-test results. Table 3 displays significant ANOVA, *t*-test and post-hoc results (i.e. $p < .05$). Insignificant test results are not report but available from the authors upon request.

4.1.1 Cost aspects (component 1)

Component 1 represents cost aspects or economic considerations behind the RHS adoption motivation. This dimension refers to the relevance of cost-related variables, such as total costs, maintenance costs, payback period, investment costs, and current and expected future energy prices.

Table 3 shows for adopters segmented according to the *adopted RHS* that cost aspects are a relatively less important motivational factor for adopters of GAS-ST. In contrast, costs have a relatively high relevance for adopters of WOOD. This reflects differences in e.g. the purchase and operating costs of these systems or in the average income of the adopters. For *type of the home*, we find that adopters in newly built homes perceive cost aspects as less important compared to adopters in existing homes. A possible explanation can be that RHS-related costs represent only a relatively small part of the overall costs related to a newly built home and, therefore, are considered as less relevant. Adopters in homes with a relatively high *energy standard* may perceive cost aspects as less important, due to the somewhat lower energy requirements of such homes. Finally, for *size of the home*, we find that adopters in larger homes seem to care more about cost aspects related to the RHS. Reasons for that can be the higher overall energy requirements and the need for a RHS with a relatively larger dimensioning.

4.1.2 General attitude towards the RHS (component 2)

The second component describes the adopters' general attitude towards the RHS. Perceptions about the RHS's compatibility with existing habits and daily routines, the ease of use, as well as the usefulness and the understandability, are covered by this dimension. According to table 3, we only find little evidence for differences in the RHS adoption motivation between groups of adopters. Thus, this component seems to be almost equally important for all RHS adopters.

4.1.3 Government grant (component 3)

Component 3 represents the government grant. This dimension refers to variables covering the importance of the capital grant provided by BAFA for the decision and the relevance of lowered investment costs by receiving the grant.

According to table 3, we find for *adopted RHS* that the government grant has is less important for adopters of GAS-ST and HEAT-P, while it has a higher relevance for adopters of WOOD and OIL-ST. Reasons for that can be the relatively higher purchase costs of WOOD or the lower average income of adopters of OIL-ST and WOOD. For *type of the home*, the capital grant is less relevant for adopters in newly built homes. As for cost aspects, we argue that the capital grant covers only a relatively small part of the overall costs when constructing a newly built home. In contrast, the grant covers a relatively higher share of the costs linked to the replacement of a RHS in an existing home. Similar to the findings for the component cost aspects, the BAFA grant is more relevant for homes with a lower *energy standard*. Moreover, the BAFA grant is less important for adopters in *1-family homes* compared to adopters in 2-family or row homes. Reasons for that can be the smaller dimensioning (and, thus, lower purchase costs) of RHS in 1-family homes. As expected, the grant is more important for adopters with a lower *monthly net income*.

4.1.4 Reactions to external threats (component 4)

Reactions to external threats, such as environmental problems and geopolitics, are represented by component 4. This includes considerations related to energy supply security (i.e. independency from fluctuating energy prices or politically motivated supply crises of oil and gas) or environmental protection.

Table 3 shows that the *adopted RHS* has a strong impact on the influence of this component on the adoption motivation. This reflects the type of fuel used by the system concerned. As expected, adopters that use the fossil fuels natural gas or oil for heating are less motivated by external threats than adopters that use the renewable energy source wood pellets as a fuel. For *size of the home*, we find this component to be a less relevant motivational factor for adopters in smaller homes. A possible reason can be that smaller homes consume less energy and, thus, are less exposed to (or contribute relatively less to) external threats related to the usage of fossil fuels.

4.1.5 Comfort considerations (component 5)

Component 5 contains comfort considerations with respect to the RHS. This includes the relevance of perceived efforts linked to maintenance requirements and fuel acquisition or an improved utility value respectively quality of living conditions of the home.

Table 3 shows for *adopted RHS* that adopters of WOOD and OIL-ST care relatively less about comfort than adopters of GAS-ST and HEAT-P. For *type of the home*, we find that adopters in newly built homes are more motivated by comfort considerations than adopters in existing homes. Likewise, for the *energy standard of the home*, we find that adopters that own a non-renovated home are less motivated by comfort considerations than adopters in a home with an energy standard of a newly built or a low-energy home. Reasons for that can be that adopters having a home with a better energy standard either carried out a major retrofit or constructed a new home. Therefore, they are probably already used to a higher home comfort and, therefore, prefer a RHS with a comparable comfort. For the variable *monthly net income of the household*, we find that comfort considerations are more important for adopters with a very low income. A possible reason can be that low-income adopters have up to now experienced a relatively lower RHS-related comfort level (e.g. RHS-specific experience is so far linked to outdated or malfunctioning RHS based on oil, coal or electricity) than adopters with a higher income.

4.1.6 Influence of peers (component 6)

The sixth component represents the influence of peers or the impact of subjective norms on the decision in favor of a RHS. This dimension refers to variables such as the relevance and influence of neighbors, friends or colleagues on the decision, the number of peers with the specific RHS, and the desire to improve one’s image by adopting a specific RHS.

For the influence of peers, we find no statistically significant differences between any groups of adopters. Thus, the impact of this component on the motivation to adopt a certain RHS seems to be similar for all groups of adopters in our sample.

4.2 Characterizing the RHS adopter

Hierarchical cluster analysis groups the 2347 observations into three clusters: (1) the convenience-oriented (54.4%), (2) the consequences-aware (32.2%), and (3) the multilaterally-motivated RHS adopter (13.4%). Table A-3 in the appendix gives an overview of the summary statistics for the full sample and the three identified RHS adopter clusters.

We tested the clusters for homogeneity by calculating the *F*-values[6] for the six segmentation variables. A cluster is considered completely homogeneous if all *F*-values are smaller than one (i.e. variance of the variable within the cluster is smaller than the variance of the same variable in the survey population). We find that all clusters are nearly homogeneous, i.e. each cluster had five segmentation variables with *F*-values smaller than one.[7] ANOVA revealed a significant effect of the identified homeowner clusters for each segmentation variable ($p < .001$). This indicates that there are significant differences between the three clusters. We further explored the differences between pairs of clusters by post-hoc tests. Table 4 summarizes the results of the cluster analysis and post-hoc tests.

Table 4: Characterization of RHS adopter clusters by segmentation variables

Segmentation variable	ANOVA[1]	Post-hoc tests[2]		C1	C2	C3
		Groups	*d*	Mean	Mean	Mean
Cost aspects	$F(2, 943.565) = 505.83$ ($p < .001$) $\eta^2 = .26$: strong	C1 - C2 C1 - C3 C2 - C3	-.71: moderate -1.66: large -1.08: large	-.40	.23	1.06
General attitude towards the RHS	$F(2, 884.500) = 120.63$ ($p < .001$) $\eta^2 = .09$: medium	C1 - C2 C1 - C3 C2 - C3	.43: small -.57: moderate -.91: large	.06	-.36	.57
Government grant	$F(2, 799.541) = 416.75$ ($p < .001$) $\eta^2 = .27$: strong	C1 - C2 C1 - C3 C2 - C3	-.57: moderate -1.95: large -1.14: large	-.37	.11	1.18
Reactions to external threats	$F(2, 933.398) = 260.96$ ($p < .001$) $\eta^2 = .17$: strong	C1 - C2 C1 - C3 C2 - C3	-.89: large -.80: large $p > 0.05$	-.37	.47	.44
Comfort considerations	$F(2, 901.795) = 785.63$ ($p < .001$) $\eta^2 = .35$: strong	C1 - C2 C1 - C3 C2 - C3	1.31: large -.71: moderate -2.39: large	.26	-.81	.86
Influence of peers	$F(2, 838.550) = 57.10$ ($p < .001$) $\eta^2 = .05$: weak	C1 - C2 C1 - C3 C2 - C3	-.11: very small -.68: moderate -.60: moderate	-.13	-.02	.56

Notes: C1: convenience-oriented RHS adopters, C2: consequences-aware RHS adopters, C3: multilaterally-motivated RHS adopters; **[1]** Welch *F*-test in all cases; **[2]**: $p < .05$ if not stated otherwise

[6] The *F*-value is the quotient of the variance of a variable within a cluster and the variance of the variable in the survey population (Backhaus, 2011).

[7] For cluster 1, the *F*-value of the segmentation variable "*reactions to external threats*" was 1.15, for cluster 2, the *F*-value of "*general attitude towards the RHS*" was 1.20, and for cluster 3 the *F*-value of "*influence of peers*" was 1.05.

For all 25 items included in the PCA, we calculated the *t*-values for each cluster. Positive *t*-values indicate that a variable is overrepresented in the cluster compared to the full sample and vice versa. This kind of analysis allows a more detailed investigation of differences between the identified clusters. Figure 1 illustrates the comparison of the three clusters by means of *t*-values.

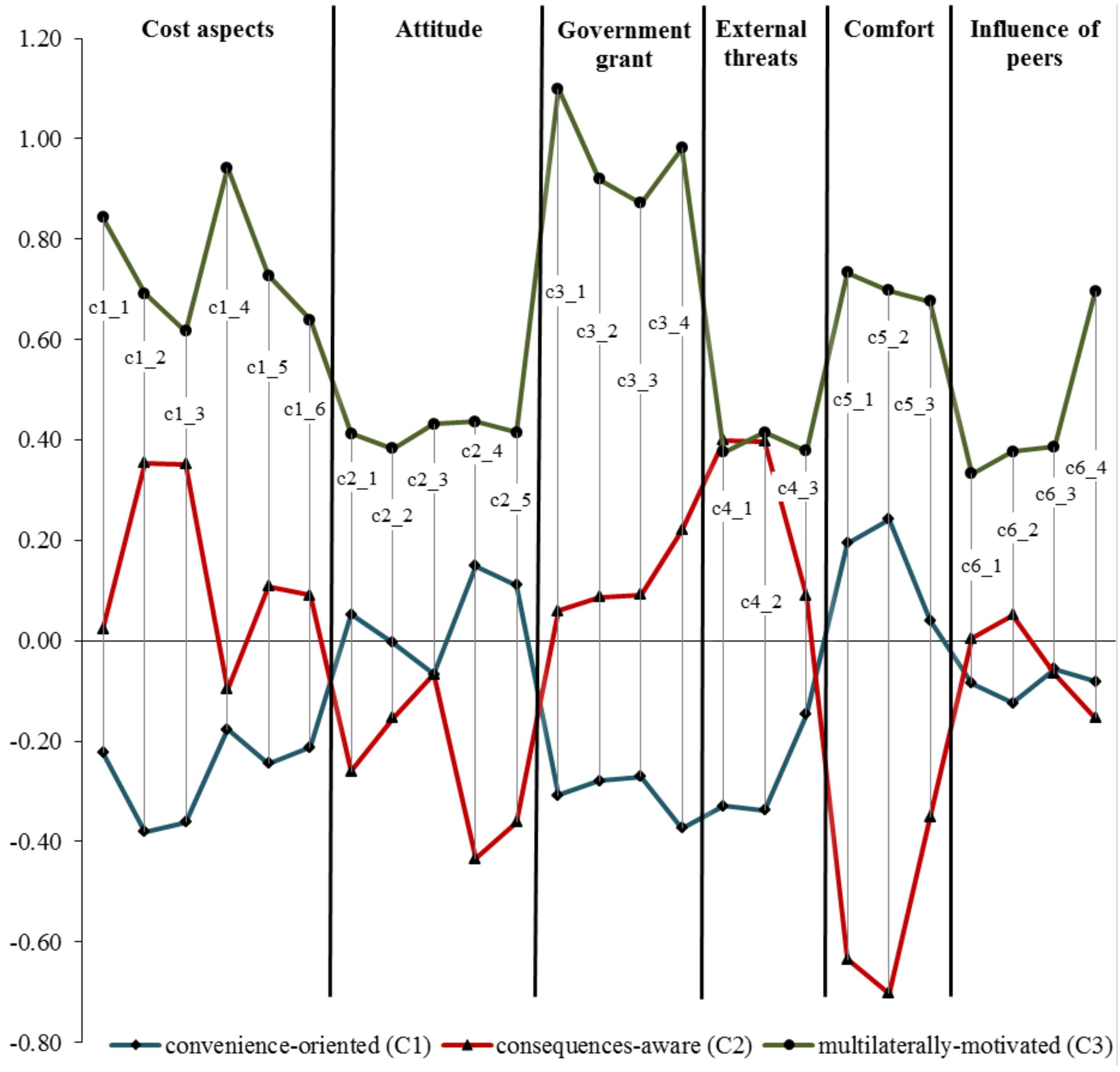

Figure 1: Comparison of *t*-values for all 25 items included in the PCA (classified according to the six extracted components)

Furthermore, we predicted the probability of belonging to one of the three clusters by means of a multinomial logit model (MNL). We used cluster membership as dependent variable and selected home and socio-demographic characteristics as independent variables. Table 5 presents the MNL results as average marginal effects (M.E.).

Table 5: Results of the MNL analysis for predicting cluster membership

	Cluster 1			Cluster 2			Cluster 3		
	M.E.		S.E.	M.E.		S.E.	M.E.		S.E.
GAS-ST	0.064		0.040	**-0.096**	**	**0.038**	0.033		0.035
HEAT-P	**-0.132**	***	**0.036**	0.026		0.039	**0.105**	***	**0.035**
WOOD	**-0.398**	***	**0.035**	**0.330**	***	**0.044**	**0.068**	*	**0.036**
Newly built home	**0.093**	***	**0.027**	-0.020		0.026	**-0.072**	***	**0.019**
1-Family home	0.114		0.027	0.017		0.024	-0.029		0.020
Size	-0.014		0.011	0.004		0.010	0.010		0.008
Energy Consultant	**-0.036**	*	**0.021**	0.000		0.020	**0.035**	**	**0.016**
Female	**0.071**	***	**0.027**	**-0.082**	***	**0.025**	0.011		0.020
University degree	**-0.052**	**	**0.023**	**0.066**	***	**0.022**	-0.015		0.017
Age	0.006		0.027	-0.004		0.005	-0.002		0.004
Income	0.002		0.009	**0.016**	*	**0.008**	**-0.018**	***	**0.007**
East Germany	0.036		0.033	-0.047		0.031	0.011		0.025
South Germany	0.004		0.022	-0.006		0.021	0.002		0.016
Rural	-0.004		0.022	-0.002		0.021	0.006		0.016
Log-likelihood	-1798.605								
Pseudo-R^2	0.103								
N	2088								

Notes: Average Marginal Effects (M.E.), Superscripts ***, ** and * indicate statistical significance at the 1%, 5% and 10% level, respectively. Reference categories: OIL-ST for GAS-ST, HEAT-P and WOOD.

Based on a comparison of the *t*-values and the results from the MNL analysis, we briefly describe and characterize the three clusters of RHS adopters.

4.2.1 Convenience-oriented RHS adopter (cluster 1)

The convenience-oriented RHS adopter characterizes the largest group in our sample (54.4%). For homeowners in this cluster, the RHS should fit well into the daily routine and should not require much further attention. Thus, the decision between competing RHS is mainly motivated by *comfort considerations* and the *general attitude towards the RHS*. Figure 1 shows that convenience-oriented RHS adopters prefer to have a low effort related to the overall handling (c2_4, c2_5), fuel acquisition (c5_1) and maintenance requirements of the RHS (c5_2). In contrast, *cost aspects*, the *government grant*, *external threats* and the influence of peers are less relevant drivers of the adoption motivation.

According to table 5, adopters in this cluster are less likely of adopting HEAT-P (-0.132^{***}) and WOOD (-0.398^{***}). Moreover, adopters in this cluster tend to own a newly built home (0.093^{***}) and are also less expected to ask an energy consultant for advice (-0.036^{*}). Females are more likely to be convenience-oriented RHS adopters (0.071***). Finally, members of this cluster tend not to have a university degree (-0.052**).

4.2.2 Consequences-aware RHS adopter (cluster 2)

The second-largest group (32.2%) contains consequences-aware RHS adopters. The RHS adoption decision is driven by taking into account short- (financial benefits and costs related to the adoption decision) and long-term consequences (e.g. rising energy prices, energy supply security, and environmental protection). This includes avoiding financial disadvantages by considering different RHS-related costs and the capital grant. Moreover, homeowners in this segment try to circumvent risks stemming from a high dependency on fossil fuels (e.g. fluctuating energy prices). In particular, figure 1 shows that aspects related to energy prices (c1_2, c1_3, c4_1, c4_2) seem to be an important factor of the RHS adoption motivation. The *general attitude towards the RHS* and *comfort considerations* are less relevant for the adoption motivation in this cluster.

Table 5 shows that adopters in this group tend to choose WOOD (0.330***) while GAS-ST (-0.096**) is less likely chosen. For the socio-demographic characteristics, we find that females are less likely to be members of this cluster (-0.082***). Finally, we find that adopters in this cluster tend to have a university degree (0.066***) and a higher income (0.016*).

4.2.3 Multilaterally-motivated RHS adopter (cluster 3)

The smallest cluster (13.4%) contains multilaterally-motivated RHS adopters. Adopters in this cluster strongly engage in the decision between competing RHS. As figure 1 shows, they base their decision on a variety of aspects (in particular *cost aspects*, *government grant,* and *comfort considerations*). Moreover, the motivational factor "*influence of peers*" seems to be of a relatively high relevance in this cluster. Adopters in this cluster tend to choose HEAT-P (0.105***) or WOOD (0.068*) as RHS and are less likely to own a newly built home (-0.072***). Moreover, adopters in this cluster tend to ask an energy consultant for advice (0.035**). Finally, the probability of belonging to this cluster decreases with a higher income (-0.018***).

5 Discussion and conclusions

The purpose of this research was to empirically investigate motivational factors influencing the homeowners' decisions between competing RHS. This is particularly important since space heating demand represents a large fraction of the households' overall energy demand and, thus, is the main source of CO_2 emissions in the residential buildings sector.

Consequently, a better understanding of the adoption of energy-efficient and renewable energy sources-based RHS by private homeowners is of high energy policy relevance. Until now, most studies in this field have used stated preference data on hypothetical RHS adoption decisions. Only relatively little scientific research has so far empirically analyzed the homeowners RHS adoption motivation by means of a sound theoretical framework and data on real adoption decisions. Therefore, our study for Germany makes a significant empirical contribution towards a better understanding of the RHS adoption motivation at the level of the individual homeowner.

In the following, we briefly answer the research questions of our study and discuss their implications. First, we show that there are six components that constitute the homeowners' motivation to adopt a certain RHS out of a set of competing alternatives. These components reflect well certain elements of theories on individual decision-making (cf. section 2.1). We show that elements related to the individual attitude towards the RHS as well as the influence of peers (i.e. subjective norms) influence the adoption motivation. Moreover, our findings confirm that the RHS adoption motivation does not only have the character of rational decision-making but also has an emotional (i.e. psychological and cognitive) characteristic. Dimensions that are characterized by rational decision-making are of an economic nature and include the components *cost aspects* and *government grant*. Considerations related to the government grant are deliberately separated from general economic aspects, such as costs, the payback period, or energy prices. This shows that the capital grant provided by BAFA has a differentiated effect on the motivation to adopt a RHS (i.e. the grant seems to be an important aspect in the homeowners' decision making). Dimensions that include psychological or cognitive aspects cover the components *general attitude towards the RHS*, *reactions to external threats*, *comfort considerations* and the *influence of peers*. These components also have a non-economic nature. *General attitude towards the RHS* and *influence of peers* are broader dimensions, while *reactions to external threats* and *comfort considerations* are more specific. Second, our analysis reveals that there are differences in our sample regarding the RHS adoption motivation between selected groups of homeowners. In particular, we find evidence for differences between groups that were segmented according to certain home characteristics. We can observe a differentiated impact of the adopted RHS or type of home (newly built or existing home) on the components *cost aspects*, *government grant*, and *comfort considerations*. Moreover, the home characteristics "energy standard" and "dwelling size" are also found to have an influence on the adoption motivation. In contrast, we only find little evidence for the effect of socio-demographic characteristics. More specifically, we find a weak influence of household income on the components *general attitude towards the RHS*, *government grant*, and *comfort considerations*. Thus, differences in the relevance of certain components for the RHS adoption motivation can mainly be explained by home characteristics and household income. In general, we find no differences in the RHS adoption motivation between groups of homeowners that are separated according to their geographical location (e.g. East or South Germany). Finally, we show that there are three clusters of homeowners that differ in their RHS adoption motivation. The largest group includes *convenience-oriented RHS adopters*. RHS adopters in this group mainly care about the comfort and suitability of the RHS to their daily routines. Economic considerations (e.g. RHS-specific costs or the amount of the grant) or energy supply security issues are less relevant drivers of the adoption decision. This shows that existing habits or the compatibility of the RHS with daily routines is most relevant for a large group of homeowners. Typically, adopters in this group are more likely to choose more established and proven RHS, such as the gas -fired condensing boiler with solar thermal support. The second largest group covers *consequences-aware RHS adopters*. Adopters in this cluster specifically care about short- (financial benefits and costs) and long-term consequences (rising energy prices, energy supply security, and environmental protection) of their decision. In particular, considerations related to today's and the future's energy prices seem to be important. Adopters in this cluster are typically more likely to adopt innovative RHS such as the wood pellet-fired boiler. Finally, the smallest cluster contains *multilaterally-motivated RHS adopters*. Members of this group strongly engage in the adoption decision by considering a variety of aspects. The heat pump and wood pellet-fired boiler are chosen relatively more frequently in this cluster. Thus, the large majority of RHS adopters do not consider all motivational factors as equally important, but they rather limit their decision-making to some aspects only.

However, there are also some limitations of our research. Most of the restrictions stem from our dataset (e.g. not all possible types of RHS covered, period of time considered limited to 01/2009 – 08/2010, focus on BAFA capital grant recipients only) which may somewhat reduce the representativeness of our study (cf. section 3.1). Other limitations are related to the theoretical framework of our study. This includes that the focus of our research is on the RHS adoption motivation only. Nevertheless, in some cases the RHS adoption decision is embedded into a bundle of different decisions linked to other energy-related aspects of a residential building (e.g. insulation standard or type of windows). Moreover, the survey covers motivational factors that were identified from the literature and by practical considerations only (cf. section 2.2). There may also be limitations related to the survey methodology including the common method bias (cf. section 3.1). Finally, the results of our study have to be interpreted in the light of the external framework conditions during the period of time considered (e.g. energy prices, regulatory framework, financial support mechanisms).

A number of conclusions can be derived from our research. First, we can draw some economic efficiency implications from our research. The results show that the impact of the BAFA grant on the RHS adoption motivation differs between groups of homeowners. Rather than distributing the financial resources available in a relatively non-selective way (i.e. also to homeowners where the grant appears to have limited relevance for the adoption motivation), we suggest that the grant explicitly considers the heterogeneity of RHS adopters. Therefore, the amount of the capital grant can be determined by the adopted RHS, specific home characteristics (e.g. targeting existing homes or homes with a low energy standard), or socio-demographic characteristics (e.g. targeting low income or retired homeowners). Moreover, a sufficiently high grant size may set incentives for overcoming existing habits and routines. Second, the identified dimensions behind the RHS adoption motivation offer different channels for influencing the homeowners' decision in favor of a certain RHS. This has implications for both the design of policy instruments and the marketing strategies of RHS manufacturers. Energy and climate policy instruments targeting the residential building sectors in general, and innovative RHS in particular, can be made more effective by explicitly addressing the different dimensions of the homeowners' RHS adoption motivation. This requires a balanced bundle of targeted policy instruments. On the one hand, such instruments may consider elements of an economic nature by means of capital grants, low interest loans, or tax reductions. On the other hand, emotional or cognitive aspects of the RHS adoption decision can be addressed through information dissemination activities (e.g. information campaigns) related to specific (non-economic) aspects of innovative RHS or the demonstration of innovative RHS within the framework of showcase projects or home fairs. Moreover, regulatory measures (e.g. requirements to use a certain share of renewables-based heat supply) can also help to overcome persisting habits and norms. Further, our results have some managerial implications. The identified motivational factors offer different starting points for marketing campaigns of RHS manufacturers (e.g. addressing aspects related to comfort, convenience or energy supply security). Finally, we can conclude that the biggest challenge for policy-makers and marketing strategies of RHS manufacturers lies in overcoming existing habits as well as misperceptions about the suitability and convenience of the RHS.

Lastly, our results can also be applied in future research. For example, the identified motivational factors and clusters of RHS adopters can be used for operationalizing a conceptual model on the homeowners’ RHS adoption motivation. Based on a confirmatory research approach, such as structural equation modeling, this would allow testing different hypotheses and causal relationships between the motivational factors, clusters and/or external variables. Moreover, the results from our empirical analysis can also be used as an input for a multi-agent simulation model for investigating the diffusion of competing RHS.

Appendix

Table A-1: Factor extraction according to Kaiser Criterion (7 components), Horn's Parallel Analysis (6 components) and MAP Test (6 or 4 components)

Component no.	**Kaiser Criterion (eigenvalues-greater-than-one rule)**			**Horn's Parallel Analysis**		**MAP Test (average partial correlations)**		
	Eigenvalue	% of variance	Cumulative %	Mean random data eigenvalues	Percentile random data eigenvalues	No. of components partialled out	Original (1976) r^2	Revised (2000) r^4
1	4.560	18.242	18.242	1.1857	1.2116	.0000	.0377	.0070
2	2.857	11.429	29.671	1.1589	1.1785	1.0000	.0244	.0032
3	1.907	7.630	37.301	1.1387	1.1559	2.0000	.0192	.0023
4	1.749	6.998	44.299	1.1209	1.1361	3.0000	.0210	.0018
5	1.635	6.541	50.839	1.1046	1.1188	4.0000	.0216	.0014
6	1.556	6.224	57.063	1.0894	1.1029	5.0000	.0210	.0014
7	1.016	4.063	61.126	1.0747	1.0880	6.0000	.0173	.0016
8	.866	3.465	64.591	1.0612	1.0732	7.0000	.0197	.0022
9	.805	3.220	67.811	1.0477	1.0594	8.0000	.0224	.0036
10	.760	3.041	70.852	1.0347	1.0454	9.0000	.0273	.0074
11	.741	2.963	73.816	1.0221	1.0339	10.0000	.0340	.0098
12	.653	2.611	76.427	1.0094	1.0203	11.0000	.0392	.0113
13	.636	2.543	78.970	.9970	1.0081	12.0000	.0479	.0168
14	.628	2.511	81.481	.9848	.9957	13.0000	.0582	.0192
15	.590	2.359	83.840	.9725	.9831	14.0000	.0687	.0273
16	.521	2.083	85.923	.9600	.9721	15.0000	.0772	.0402
17	.515	2.061	87.984	.9477	.9590	16.0000	.0917	.0421
18	.488	1.954	89.938	.9349	.9469	17.0000	.1146	.0545
19	.476	1.904	91.842	.9229	.9348	18.0000	.1351	.0650
20	.414	1.656	93.499	.9097	.9223	19.0000	.1672	.0881
21	.394	1.577	95.076	.8961	.9090	20.0000	.2125	.1162
22	.369	1.478	96.553	.8820	.8954	21.0000	.2895	.1806
23	.329	1.315	97.868	.8666	.8807	22.0000	.3399	.2218
24	.307	1.227	99.096	.8501	.8646	23.0000	.5335	.4130
25	.226	.904	100.000	.8276	.8464	24.0000	1.0000	1.0000

Notes: Specifications for Horn's Parallel Analysis: No. of cases: 2440, no. of variables: 25, no. of datasets: 1000, percent: 95

Table A-2: Correlation matrix for the extracted components

	Cost aspects	General attitude	Government grant	External threats	Comfort	Peers
Cost aspects	1.000					
General attitude	.122	1.000				
Government grant	.385	.061	1.000			
External threats	.188	.145	.157	1.000		
Comfort	.079	.252	.063	.030	1.000	
Peers	.146	.069	.219	.093	.112	1.000

Table A-3: Summary statistics of socio-demographic, home and spatial characteristics for the full sample used for the PCA and clusters 1-3

Characteristic	**Categories**	**Full sample** *N*=2440	**Cluster 1** *N*=1276	**Cluster 2** *N*=755	**Cluster 3** *N*=316
Adopted RHS	*GAS-ST*	28.4%	38.2%	13.8%	20.3%
	OIL-ST	10.5%	12.2%	7.8%	8.5%
	HEAT-P	36.5%	38.4%	32.6%	42.7%
	WOOD	24.5%	11.2%	45.8%	28.5%
Newly built home	*Yes = 1; No = 0* (existing home)	41.6%	49.4%	35.6%	33.2%
Size of the home	*< 100 m^2*	4.0%	4.1%	3.9%	4.2%
	100 to 149 m^2	42.6%	47.0%	38.3%	35.1%
	150 to 199 m^2	30.2%	29.0%	30.1%	34.8%
	200 to 249 m^2	15.7%	13.3%	19.1%	17.9%
	> 250 m^2	7.5%	6.6%	8.6%	8.0%
1-family home	*Yes = 1; No = 0* (2-family or row house)	75.6%	79.0%	74.5%	68.4%
Energy standard of the home	*Non-renovated home*	21.6%	19.1%	23.2%	23.6%
	Renovated home	25.0%	20.4%	28.5%	32.2%
	Standard of an average newly built home	24.3%	29.4%	19.2%	18.6%
	Low energy home	28.0%	29.9%	28.2%	23.9%
	Passive house	1.1%	1.1%	0.8%	1.7%
Female	*Yes = 1; No = 0* (male)	16.6%	18.9%	12.8%	17.0%
Energy consultant	*Yes = 1; No = 0* (no energy consultant)	39.6%	38.2%	40.4%	45.2%
University degree	*Yes = 1; No = 0* (no university degree)	35.5%	35.1%	40.0%	29.8%
Age of the adopter	*35 and younger*	14.8%	16.4%	12.9%	16.2%
	35 – 39	13.4%	14.9%	13.0%	10.0%
	40 – 44	14.4%	14.6%	15.1%	12.9%
	45 – 49	14.5%	12.1%	17.6%	16.2%
	50 – 54	11.4%	10.8%	11.3%	11.7%
	55 – 59	10.8%	9.6%	12.3%	10.4%
	60 – 64	8.3%	8.9%	7.5%	8.4%
	65 and older	12.4%	12.8%	10.3%	14.2%
Monthly net income of the household	*< €2000*	13.3%	13.2%	10.9%	18.1%
	€2000-2999	31.6%	31.9%	29.5%	33.0%
	€3000-3999	27.1%	27.6%	27.7%	26.2%
	€4000-4999	14.9%	13.8%	17.0%	14.9%
	€5000-5999	6.6%	6.7%	8.1%	3.9%
	> €6000	6.4%	6.7%	6.8%	3.9%
South Germany	*Yes = 1; No = 0* (rest of Germany)	40.0%	36.2%	45.9%	41.7%
East Germany	*Yes = 1; No = 0* (rest of Germany)	12.1%	13.9%	9.3%	13.1%
Rural region	*Yes = 1; No = 0* (urban region)	35.8%	34.3%	37.0%	39.4%

Notes: Cluster 1: convenience-oriented RHS adopters, Cluster 2: consequences-aware RHS adopters, Cluster 3: multilaterally-motivated RHS adopters

References

Ajzen, I. (1991), The theory of planned behavior, *Organisational Behavior and Human Decision Processes*, 50(2), 179-211.

Ajzen, I. and Fishbein, M. (1980), *Understanding Attitudes and Predicting Social Behavior*, Engelwood-Cliffs: Prentice-Hall.

Axsen, J., TyreeHageman, J. and Lentz, A. (2012), Lifestyle practices and pro-environmental technology, *Ecological Economics*, 82(1), 64-74.

Backhaus, K., Erichson, B., Plinke, W. and Weiber, R. (2011), *Multivariate Analysemethoden. Eine anwendungsorientierte Einführung.* Heidelberg: Springer.

Barr, S., Gilg, A.W. and Ford, N. (2005), The household energy gap: examining the divide between habitual- and purchase-related conservation behaviours, *Energy Policy*, 33(11), 1425–1444.

Bergs, S. (1981), Optimalität bei Cluster-Analysen: Experimente zur Bewertung numerischer Klassifikationsverfahren, Disseration, University of Muenster.

BDEW – Bundesverband der Energie- und Wasserwirtschaft e.V. (2009), Energiemarkt Deutschland. Zahlen und Fakten zur Gas-, Strom- und Fernwärmeversorgung. Sommer 2009, [Online] Available at: http://www.bdew.de/bdew.nsf/id/DE_Energiemarkt_Deutschland_-_Sommer_2009/$file/09%2011%2009%20Energiemarkt_2009.pdf [accessed November 29, 2012].

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

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.

Cohen, J. (1988), Statistical Power Analysis for the Behavioral Sciences, 2nd Edition., Hillsdale: Lawrence Erlbaum Associates.

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

Decker, T.A., Zapilko, M. and Menrad, K. (2010), Purchasing behaviour related to heating systems in Germany with special consideration of consumers' ecological attitudes. The Bioenergy Association of Finland (FINBIO) (Ed.): Forest Bioenergy 2010. Book of Proceedings, Volume 47, 25-33.

Decker, T.A. (2010), Konsumentenverhalten beim Kauf eines privaten Gebrauchsguts am Beispiel Heizung, In: Menard, K. (Ed.): Nachwachsende Rohstoffe in Forschung und Praxis, Volume 3, Straubing: Verlag Attenkofer.

Dubin, J.A. and McFadden, D. (1984), An econometric analysis of residential electric appliance holdings and consumption, *Econometrica*, 52(2), 345-362.

Dunlap, R.E. and Van Liere, K.D. (1978), The new environmental paradigm: a proposed measuring instrument and preliminary results, *Journal of Environmental Education*, 9(4), 10-19.

EEWärmeG - Act on the Promotion of Renewable Energies in the Heat Sector (Erneuerbare-Energien-Wärmegesetz – EEWärmeG) of 2008 (2008), [Online] Available at: http://www.erneuerbare-energien.de/files/english/pdf/application/pdf/ee_waermeg_en.pdf [accessed November 29, 2012].

Faiers, A., Cook, M. and Neame, C. (2007), Towards a contemporary approach for understanding consumer behaviour in the context of domestic energy use, *Energy Policy*, 35(8), 4381-4390.

Gilg, A. and Barr, S. (2006), Behavioural attitudes towards water saving? Evidence from a study of environmental actions, *Ecological Economics*, 57, 400-414.

Goto, H., Goto, M. and Sueyoshi, T. (2011), Consumer choice on ecologically efficient water heaters: Marketing strategy and policy implications in Japan, *Energy Economics*, 33(4), 195-208.

Guiot, D. and Roux, D. (2010), A Second-hand Shoppers' Motivation Scale: Antecedents, Consequences, and Implications for Retailers, *Journal of Retailing*, 86(4), 355-371.

Langniß, O., Schüller, M., Wülbeck, H.-F., Nast, M., Pehnt, M., Frick, S., Drück, H., Streicher, E., Hartmann, H., Reisinger, K. (2010), Evaluierung von Einzelmaßnahmen zur Nutzung erneuerbarer Energien im Wärmemarkt (Marktanreizprogramm) für den Zeitraum 2009 bis 2011. Evaluierung des Förderjahres 2009. Study commissioned by Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, [Online] Available at: http://www.fichtner.de/pdf/MAP-Evaluationsbericht_2009.pdf, [accessed November 29, 2012].

Lillimo, S.C., Alfnes, F., Halvorsen, B. and Wik M. (2011), Factors Affecting Norwegian Households‘ Heating Investments. Paper presented at *Project Bioenergy Markets – Workshop Oslo*, 24-25 October 2011.

Madlener, R. and Artho, J. (2005), *Sozioökonomische Barrieren der Holzenergie-Nutzung im genossenschaftlichen Wohnungswesen in der Schweiz auf Entscheidungsträgerebene,* In: V. Täube (Ed.), Aspekte der Innovation and Innovationsdiffusion, Beiträge zur Tagung "Diffusion und Folgen von technischen und sozialen Innovationen" vom 11./12. März 2005 (pp. 21-37), Tagungsband, Reihe "Statistik der Schweiz", Neuenburg: Bundesamt für Statistik.

Madlener R. and Harmsen - van Hout M.J.W. (2011), Consumer Behaviour and the Use of Sustainable Energy, In: Galarraga, I., González-Eguino, M. and Markandya, A., *Handbook of Sustainable Energy*, Edward Elgar Publishing, Cheltenham (UK)/Northampton (Mass./US), Chapter 10, pages 181-210.

Mahapatra, K. and Gustavsson, L. (2007), Influencing Swedish homeowners to adopt district heating system, *Applied Energy*, 86(2), 144-154.

Mahapatra, K. and Gustavsson, L. (2008), An adopter-centric approach to analyze the diffusion patterns of innovative residential heating systems in Sweden, *Energy Policy,* 36(2), 577-590.

Mahapatra, K. and Gustavsson, L. (2009), Adoption of innovative heating systems—needs and attitudes of Swedish homeowners, *Energy Efficiency*, 3(1), 1-18.

Mayer, H. and Flachmann, C. (2008), Energieverbrauch der privaten Haushalte 1995 bis 2006, *Wirtschaft und Statistik 12/2008.* 1107-1115.

Michelsen, C.C., Madlener, R. (2012). Homeowners' Preferences for Adopting Innovative Residential Heating Systems: A Discrete Choice Analysis for Germany, *Energy Economics*, 34(5): 1274-1283.

Milligan, G. W. and Cooper, M. C. (1985), An Examination of Procedures for Determining the Number of Clusters in a Data Set, Psychometrika, 50, 159–179.

Mills, B.F. and Schleich, J. (2009), Profits or Preferences? Assessing the adoption of residential solar thermal technologies, *Energy Policy*, 37(10), 4145-4154.

Moore, G. and Benbasat, I. (1991), Development of an instrument to measure the perceptions of adopting an information technology innovation, *Information Systems Research*, 2(3), 192-222.

Nunnally, J.C. (1978). *Psychometric theory* (2nd ed.). New York: McGraw-Hill.

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.

O'Connor, B.P. (2000), SPSS and SAS Programs for Determining the Number of Components Using Parallel Analysis and Velicer's MAP Test, *Behavior Research Methods, Instruments & Computers*, 32(3), 396-402.

Rijnsoeveer, F., Farla, J., Dijst, M.J. (2009), Consumer car preferences and information search channels, *Transportation Research Part D*, 14(5), 334-342.

Rogers, E. (2003), *Diffusion of Innovations*, 5th Ed., New York: The Free Press.

Rouvinen, S., Matero, J. (2012), Stated preferences of Finnish private homeowners for residential heating systems: A discrete choice experiment, Biomass and Bioenergy, http://dx.doi.org/10.1016/j.biombioe.2012.10.010.

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.

Schwartz, S.H. (1997), Normative influences on altruism. In: Berkowitz, L. (Ed.), *Advances in Experimental Social Psychology*, Volume 10, New York: Academic Press.

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.

Stern, P.C. (1999), Information, incentives and proenvironmental behavior, *Journal of Consumer Policy*, 22, 523-530.

Stern, P.C. (2000), Toward a coherent theory of environmentally significant behaviour, *Journal of Social Issues* 56(3)**,** 523-530.

Stern, P.C. (2005), Understanding individuals' environmentally significant behavior, *Environmental Law Reporter: News and Analysis*, 35(11), 10785-10790.

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

Tapaninen, A. (2008), Do Customers' Personal Attributes Matter in the Adoption of Wood Pellet Heating? *Proceedings of the IEEE International Engineering Management Conference (IEMC)*, Estoril, Portugal, June 28-30.

Tapaninen, A., Seppänen, M. and Mäkinen, S. (2009a), Characteristics of innovation: a customer-centric view of barriers to the adoption of a renewable energy system, *International Journal of Agile Systems and Management*, 4(1/2), 98-113.

Tapaninen, A., Seppänen M. and Makinen, S. (2009b), Characteristics of innovation in adopting a renewable residential energy system, *Journal of Systems and Information Technology*, 11(4), 347-366.

Vaage, K. (2000), Heating technology and energy use: a discrete continuous choice approach to Norwegian household energy demand, *Energy Economics*, 22(6), 649-666.

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.

E.ON Energy Research Center

fcn Institute for Future Energy Consumer Needs and Behavior

RWTH AACHEN UNIVERSITY

List of FCN Working Papers

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.

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 December 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). Impact of Temperature Uncertainty on the Economic 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., Christofidou G., Madlener R. (2012). The Nexus between Natural Gas Spot and Futures Prices at NYMEX: What about Non-Linear Causality?, FCN Working Paper No. 17/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

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.

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.

Hinrichs H., Madlener R., Pearson P. (2010). Liberalisation of Germany's Electricity System and the Ways Forward of the Unbundling Process: A Historical Perspective and an Outlook, FCN Working Paper No. 26/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Achtnicht M. (2010). Do Environmental Benefits Matter? A Choice Experiment Among House Owners in Germany, FCN Working Paper No. 27/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

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.

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., Gao W., 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 May 2009).

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.

Erber G., Madlener R. (2008). Impact of ICT and Human Skills on the European Financial Intermediation Sector, FCN Working Paper No. 5/2008, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September.

FCN Working Papers are free of charge. They can mostly be downloaded in pdf format from the FCN / E.ON ERC Website (www.eonerc.rwth-aachen.de/fcn) and the SSRN Website (www.ssrn.com), respectively. Alternatively, they may also be ordered as hardcopies from Ms Sabine Schill (Phone: +49 (0) 241-80 49820, E-mail: post_fcn@eonerc.rwth-aachen.de), RWTH Aachen University, Institute for Future Energy Consumer Needs and Behavior (FCN), Chair of Energy Economics and Management (Prof. Dr. Reinhard Madlener), Mathieustrasse 10, 52074 Aachen, Germany.