



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

**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

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 6  
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 6, 52074 Aachen, Germany  
Phone: +49 (0) 241-80 49820  
Fax: +49 (0) 241-80 49829  
Web: [www.eonerc.rwth-aachen.de/fcn](http://www.eonerc.rwth-aachen.de/fcn)  
E-mail: [post\\_fcn@eonerc.rwth-aachen.de](mailto:post_fcn@eonerc.rwth-aachen.de)

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

Carl Christian Michelsen<sup>1</sup> 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. 6, 52074 Aachen, Germany*

November 2011

## Abstract

Heating demand accounts for a large fraction of the overall energy demand of private households in Germany. Thus, the adoption and diffusion of energy-efficient and renewable energy sources-based residential heating systems (RHS) is of high relevance, particularly against the background of climate change, security of energy supply and increasing energy prices. Insight into the homeowners' motivation to choose a certain type of RHS from a set of competing alternatives helps to better understand and assess the dynamics of the adoption and diffusion of such technological systems as a social phenomenon. In this paper, we examine the multi-dimensionality of the homeowners' RHS adoption motivation. A questionnaire survey ( $N=2440$ ) conducted in 2010 among homeowners who had recently installed a RHS provides the empirical foundation. In order to explore the dimensionality behind 25 items capturing different motivations to select a specific RHS, we apply principal component analysis (PCA). The results show that the 25 variables can be clustered around six components, including (1) cost aspects, (2) general attitude towards the RHS, (3) the capital grant provided by the government, (4) reactions to external threats (i.e. environmental or energy supply security considerations), (5) comfort considerations, and (6) the influence of peers. Moreover, ANOVA and  $t$ -test results show that the impact of the components "cost aspects", "capital grant" and "comfort considerations" on the adoption motivation in our sample differs by homeowner group. In particular, there are marked differences between homeowners that are separated according to the type of adopted RHS or by the type of home (i.e. existing or newly built home). Likewise, net household income, dwelling size or the home's energy standard also seem to impact the relevance of certain components for the adoption motivation.

**Key words:** Residential heating systems, technology adoption motivation, consumer behavior, principal component analysis, PCA

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

---

<sup>1</sup> Corresponding author. Phone: +49 241 80 49 836; Fax: +49 241 80 49 829; E-mail addresses: CMichelsen@eonerc.rwth-aachen.de (C.C. Michelsen), RMadlener@eonerc.rwth-aachen.de (R. Madlener).

# 1 Introduction

Heating demand accounts for a large fraction of the overall energy demand of private households. 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 decision 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, space or home characteristics, *motivational elements* on the personal-sphere level seem to play a certain role in the pro-

cess 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, includes, besides economic considerations, behavioral elements as well (e.g. Stern, 2005).

In this paper, we argue that the motivations to choose a certain type of RHS, out of a set of competing RHS, cluster around different superior dimensions underlying the decision-making process.<sup>2</sup> Therefore, the following two questions guide our research: What are the components that constitute the homeowners' motivation to adopt a specific type of RHS? Are there any differences in the motivation across different groups of homeowners?

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 the RHS adoption decision.

On the data, we apply principal component analysis (PCA) on items that capture different motivational constructs in the RHS adoption decision. This allows exploring the dimensionality of the homeowners' RHS adoption motivation by means of *ex-post* data on actual RHS adoption decisions. Moreover, we compare the impact of the identified components on the RHS adoption motivation of different groups of homeowners. Our research is restricted to the four most frequently adopted types of RHS in Germany: oil- and gas-fired condensing boiler with solar thermal support, heat pump and wood pellet-fired boiler.

---

<sup>2</sup> This research does not address the issue of what motivates homeowners to invest in a new RHS. Rather, we investigate the motivation that determines the choice 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.

To the best of our knowledge, only relatively little research has been done so far to empirically examined the dimensionality of the homeowners' actual RHS adoption decisions by means of ex-post data (e.g. Decker, 2010; Decker et al., 2010; Sopha and Klöckner, 2011). Typically, research in this field uses stated preferences data on hypothetical RHS adoption decisions that stem from choice experiments (e.g. Scarpa and Willis, 2010; Claudy et al., 2011; Rouvinen and Matero, 2011). Therefore, we make a significant empirical contribution towards a better understanding of the RHS adoption motivation at the level of the individual homeowner. Moreover, 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 also be transferred to other countries aiming at reducing the CO<sub>2</sub> emissions from residential space heating.

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 motivation to adopt energy technologies with a particular focus on RHS. Section 3 outlines the research design, providing an 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 and business, and conclude with some comments on contributions, shortcomings and suggestions for future research.

## **2 Individual decision making and the motivation to adopt a technology**

This section briefly reviews and discusses major theories and models on cognitive, normative and pro-environmental behavior on the individual level in order to frame the present study. Moreover, we review empirical studies on consumer adoption motivations with a special focus on RHS. Based on this, we are able to identify the main motivational constructs linked to the adoption of RHS.

### **2.1 Theoretical approaches towards technology adoption and diffusion**

A considerable amount of research on the adoption of innovative technologies 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 Harmssen – van Hout, 2011 for a recent survey on the energy consumer behavior literature). These individual decision-making models stem from a range of research disciplines, such as economics, psychology, or sociology. In the following, we briefly review the most relevant approaches and their consequences for our research.

### 2.1.1 Cognitive and normative approaches towards technology adoption

Cognitive models and theories have their roots in the research around attitude formation and social psychology. In particular, this approach is often applied in research on the adoption of 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. The TRA belongs to the class of expectancy-value models. According to Pollard et al. (1999, p.443) these models "formalized the view that consumers' anticipated satisfaction with a product (and hence the purchase of that product) is determined by their beliefs that the product fulfills certain functions and that it satisfies some of their needs". The TRA can be modeled as follows: *Behavioral intentions* determine actual behavior and can serve as a proximal measure of behavior. 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 other words, this means "the performance of many behaviors depends not only on motivations but also on non-motivational factors like a person's ability to actually perform the behavior" (Sanhi, 1994, p.442). An implication is that attitudes and social norms do not provide a sufficient explanation of behavior, whenever control over behavior is limited by external factors or personal capabilities. The TPB tries to overcome this problem. For this purpose, the TRA is extended by the component *perceived behavioral control* (PBC) in order to capture non-motivational factors, such as the availability of resources, the ability to carry out a certain action, or environmental constraints to predict behavior more accurately. Ajzen (1991) defines PBC as a person's belief with respect to how difficult or easy performance of the behavior is likely to be. In general, the TPB states that the stronger each of the three factors (attitude, subjective norm, perceived behavioral control) is, the stronger the individual's intention to perform the behavior. However, these components are not always weighted equally when predicting an individual's behavior. According to Miller (2005), this means that depending on the individual and the context, these three factors might have very different effects on behavioral intention.

Normative decision models for pro-environmental behavior, in contrast, focus on the role of values and moral norms. Examples include Schwartz' (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 the TPB, the VBN is a theoretical framework for attitude-related research from a psychological view. It focuses on the role of values and moral

norms in a decision process. Contrary to the TPB, this approach does not account for external conditions, such as economic factors or regulatory constraints. However, the explanatory power of values or attitudes may decline in situations where decision-makers are faced with significant external conditions. It has been shown that the explanatory power of decision models that do not explicitly account for external constraints decreases when a certain behavior requires high-effort, high-cost, and high-involvement decisions (Gatersleben et al., 2002). 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.

For the case of RHS, we hypothesize that the adoption motivation (i.e. intention to adopt a certain RHS) can be divided into three underlying dimensions, including (i) the adopter's attitude towards the RHS (i.e. the adopter's personal opinion or perceptions about the RHS), (ii) perceived social norms linked to the RHS (i.e. the influence of significant others, such as family or friends) and (iii) perceived control of external constraints (i.e. the belief about how characteristics of the home or financial possibilities constrain the adoption of a RHS).

### **2.1.2 Technology adoption and diffusion as a social process**

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 motivation to adopt an innovation such as a specific RHS. Other aspects beyond cognitive assessment and rational choice, including emotional influences or socio-cultural features, also seem to be relevant for an adopter's decision (see e.g. Faiers et al., 2007). Thus, this section reviews approaches that see the adoption and diffusion of innovations as a social process (e.g. Rogers, 2003).

The leading model in this field is Rogers' (2003) diffusion of innovations (DoI) model. This model describes the adoption and diffusion of innovations as a social communication process. A number of key assumptions underlies the DoI model. The adoption decision is characterized as a process of five sequential stages, including (i) a change in knowledge and awareness, (ii) attitude formation towards the innovation, (iii) intention to a change in behavior, (iv) implementing the innovation, and (v) confirming the decision. The process is determined by prior conditions, such as values and norms. Moreover, there are feedbacks between the different stages of the decision process, which could be both internal and psychological or external and communicative. Finally, adopter characteristics and the perception of the innovation's attributes influence the formation of knowledge to attitudes. Moreover, Rogers (2003) was

one of the first researchers to present a concept for systemically characterizing innovations (perceived attributes of innovations). He introduces five different perceived attributes in order to describe the attitude formation towards an innovation (stage 2) 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). The perceived attributes of innovations are an important concept, which is 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. This concept can be used to operationalize the constructs of more general theories, such as the TPB.

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 to simplify and reduce the number of characteristics. The approach consists of 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) targets at developing a comprehensive and unified measure. They added 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).

Thus, we hypothesize that the RHS adoption motivation may include more specific dimensions that can be used to operationalize broader dimensions such as attitude or subjective norm. The dimension attitude that captures the adopter's assessment of a RHS can be operationalized by perceptions about (i) the relative advantage (i.e. comparison of certain technical or economic attributes of a RHS to those of alternative RHS), (ii) 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), (iii) result demonstrability (i.e. degree of difficulty linked to understanding and explaining the RHS) and (iv) compatibility with existing habits and norms (i.e. degree of required substantial changes in daily routines, needs, behavior or norms due to the adoption of the RHS). The influence of subjective norms can be operationalized by perceptions about the (i) visibility (i.e. usage of the RHS visible to significant others, such as neighbors or friends) and (ii) image (i.e. positive response or recognition by others due to the adoption of the RHS). Finally, the dimension that captures the influence of external constraints (i.e. perceived behavioral control) can be opera-

tionalized by perceptions about the (i) compatibility with infrastructure (i.e. characteristics of the home or financial possibilities influence the adoption of the RHS) and (ii) voluntariness (i.e. regulatory constraints impact the adoption of the RHS).

## **2.2 Empirical studies on RHS adoption by private homeowners**

Empirical studies on the adoption of RHS by private homeowners can be divided into research that draws on (i) revealed preferences data (i.e. ownership data mostly from large household surveys on the national level) and (ii) stated preferences data (i.e. data from choice experiments or surveys designed for the specific research question). 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; Michelsen and Madlener, 2011; Vaage, 2000; Mills and Schleich, 2009; Braun, 2010; Goto et al., 2011). Besides choice modeling, research on RHS adoption motivation also utilizes theoretical frameworks including Rogers' diffusion of innovations theory, Rogers' perceived attributes of innovations or similar approaches (e.g. Decker, 2010; Decker et al., 2010; Madlener and Artho, 2005; Mahapatra and Gustavsson, 2007, 2008, 2009; Sopha and Klöckner, 2011). The second strand of research primarily targets preferences related to certain attributes of RHS (e.g. Scarpa and Willis, 2010; Claudy et al., 2011; Rouvinen and Matero, 2011). In the following, we focus the review of the literature on research that considers RHS-related preferences (i.e. motivational factors) and their impact on the adoption decision.

Various studies on adoption behavior in the energy domain apply Rogers' perceived attributes of innovations (e.g. Faiers et al., 2006, on solar power systems; Labay and Kinnear, 1981, on solar power systems; Völlnik et al., 2002, on energy conservation interventions). For the case of RHS, Madlener and Artho (2005) investigate barriers to the adoption of wood chip-fired boilers among residential building cooperatives in Switzerland. The authors use Rogers' attributes of innovation and Rogers' technology diffusion model as a theoretical framework for their empirical investigation. The attribute relative advantage includes a number of different economic (RHS-related costs) and non-economic factors (e.g. space requirements, environmental considerations, effort related to fuel acquisition, energy supply security, ease of use). The findings of the study show that compatibility, social norms and relative advantage impact the attitude of residential building cooperatives towards wood chip-fired boilers. Tapaninen (2008) and Tapaninen et al. (2009a, b) apply Rogers' attributes of innovations framework on 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.

Research on RHS adoption motivation that uses a comparable theoretical framework to Rogers' perceived attributes of innovations includes Michelsen and Madlener (2011), Decker (2010), Decker et al. (2010), Mahapatra and Gustavsson (2007, 2008, 2009) and Sopha and Klöckner (2011), among others. By applying data from a survey among private homeowners in Germany that recently adopted a RHS, Michelsen and Madlener (2011) investigate the influence of preferences regarding RHS-specific attributes. They find that energy savings, independence from fossil fuels, environmental concerns and considerations related to comfort motivate homeowners to adopt a RHS. The influence of these preferences also differs across RHS and groups of homeowners. Moreover, 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. In contrast, the studies of Mahapatra and Gustavsson (2007, 2008, 2009) on the adoption of residential heating systems in Sweden use more detailed 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. Further similar studies with comparable findings include Nyrud et al. (2008) on wood stoves, Lillemo et al. (2011) on heating system investments in Norway and Woersdorfer and Kaus (2011) on solar thermal systems in Germany.

The objective of research that is based on choice experiments is primarily to investigate the willingness to pay (WTP) for selected RHS. For this purpose, the relevance of selected system attributes for the (hypothetical) choice of a RHS is investigated. Most of the studies cover attributes related to costs (e.g. investment, operating and energy costs), energy supply security (e.g. fuel price stability), environmental considerations (e.g. CO<sub>2</sub> emissions) or comfort (e.g. required work or effort related to the RHS). For example, 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 or recommendation by someone else. The results of the study show that while micro-generation adoption is positively valued by households, the WTP is insufficient to cover the actual investment costs of these systems. Furthermore, Claudy et al. (2011) analyze the influence of perceived product characteristics on homeowners WTP for micro-generation technologies, including photovoltaic panels, solar water heaters, wood pellet-fired boilers and

small wind turbines in Ireland. They find that the WTP is influenced by the homeowners' perception of product characteristics, normative influences and socio-demographic characteristics. Moreover, Rouvinen and Matero (2011) investigate the role of RHS-specific attributes in the choice of a particular RHS by a discrete-choice experiment among Finnish private homeowners. They find that investment cost is the main attribute affecting RHS choice while non-financial attributes (e.g. CO<sub>2</sub> emissions, required own work) are also important.

### 2.3 Summary and implications of the literature review

Our review of the theoretical and empirical literature shows that the homeowners' RHS adoption motivations are diverse and include both rational and emotional aspects. More general models, such as the theory of planned behavior, suggest that the adoption decision is influenced by the individual's attitude, the influence of others (subjective norms), and external factors (perceived behavioral control). In particular, the characteristics of innovations offer a framework for investigating motivations to adopt a RHS in a systematic manner. Table 1 summarizes and assigns the motivational factors identified from the empirical literature on RHS adoption to six main categories.

**Table 1:** Categorization of motivational factors identified from the empirical literature on RHS adoption

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

The literature review reveals that the motivational constructs can be divided into constructs 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 motivational constructs of an emotional (i.e. cognitive or psychological) nature on the individual (i.e. aspects related to RHS-specific attributes such as energy supply security, environmental considerations, comfort as well as the general attitude and perceptions linked ) and social level (i.e. influence of peers or social norms). 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. In particular, the literature review allows us to identify the main motivational variables (i.e. items) that seem to impact the RHS adoption decision.

### **3 Methodology**

This section briefly presents the questionnaire development and implementation. Moreover, we present and discuss the implications of the chosen methodological approach for analyzing the homeowners RHS adoption motivation.

#### **3.1 Questionnaire survey 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 literature (cf. section 2). The wording of the questions was taken from previous surveys and adjusted to the case of RHS in Germany. We mailed the questionnaires to 5000 randomly selected homeowners who had received a grant by the Federal Office of Economics and Export Control (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).<sup>3</sup>

---

<sup>3</sup> We drew a disproportional, stratified random sample out of four different groups of homeowners. The goal was to collect a representative database that covers all types of RHS in existing and newly built 1- to 2-family homes in which a RHS adoption decision was taken in the last 1-2 years. A detailed description of the development and implementation of the questionnaire can be found in Michelsen and Madlener (2011).

We were able to raise the overall response rate to 59.7% ( $N=2985$ ) by several measures including a reminder, replacement questionnaire and a small give away. For the purpose of our analysis, we excluded all observations where either the owner does not live in the home (i.e. no own usage of the home), the home is a multi-family home (i.e. not a 1- to 2-family home), or where the main RHS is not GAS-ST, OIL-ST, HEAT-P or WOOD. Moreover, we excluded an observation if at least one of the variables for the PCA was missing (casewise deletion). Therefore, the net sample for our analysis consisted of  $N=2440$  observations.

## **3.2 Analytical procedure**

This section gives an overview of and discusses the analytical procedure applied. In a first step, we outline the chosen procedure for the PCA. Finally, we present the methodology applied for comparing groups of homeowners.

### **3.2.1 Analysis of the dimensionality of the homeowner's RHS motivation**

The investigation of the dimensionality of survey data requires decisions by the researcher regarding the analytical procedure. These decisions impact the outcome of the analysis. Therefore, we briefly outline different methodological options and discuss their implications.

#### *Decision 1: Type of factoring*

In a first step, we have to decide about the type of factoring. There are three main types of factoring, including principal component analysis (PCA), principal axis factor analysis (PAF), and maximum-likelihood factor analysis (MLFA). PCA can be used to identify the common components explaining most of the overall variance in a model. In contrast, PAF and MLFA aim at explaining the relationship between a set of variables by a smaller set of factors. (e.g. Bühner, 2011, Ch.6). In our analysis, we apply PCA since we want to explore the dimensionality of the homeowners' adoption decisions (i.e. extraction of the underlying components) and aim at reducing a set of variables to a smaller set of components. PCA is a multivariate statistical method used to reduce (survey) data and to extract few latent components. It generates a set of abstract variables (i.e. principal components) in order to summarize the information in the original data. The number of generated components is smaller than the number of variables in the original data. The extracted components represent direct combinations of the original variables, while the loadings (i.e. normalized coefficients) denote the directions along which the original variables influence the extracted components. These loadings can either be positive or negative. In the literature, loadings below 0.30 are usually seen as poor (Bühner, 2011, Ch.6). Variables that can be summarized into a common component show

some similarity or relationship. PCA is performed by applying iterative algorithms or solving an eigenvalue problem.

In order to assess the suitability of the PCA to the set of initial variables, the *Kaiser-Meyer-Olkin (KMO) statistic* (which displays the degree that a model is able to explain the variance of the variables) is computed and the *Bartlett test* (which examines the hypothesis whether all variables are uncorrelated) performed. KMO statistics (range between 0 and 1) should be at least above 0.5, which means that the majority of the variance is explained by the model (Bühner, 2011, Ch.6). The Bartlett-Test should be significant. Finally, the *Measure of Sampling Adequacy (MSA)* values single variables. They have the same meaning as the KMO statistics and tell whether a single variable should be excluded from the model (i.e.  $MSA < 0.5$ ).

#### *Decision 2: Number of components to be extracted*

According to O'Connor (2000), different approaches can be used to determine the optimal number of components to be extracted (i.e. to avoid under- or over-extraction). The most common criterion used in the literature (and also in many cases the default decision rule used in most statistical software packages) is the *Kaiser criterion* or *eigenvalues-greater-than-one rule* (measuring the variance of all variables in the model that can be explained by a certain component). Other factor retention criteria include the *scree plot*<sup>4</sup>, *Horn's parallel analysis (PA)*<sup>5</sup> and *Velicer's minimum average partial (MAP) test*<sup>6</sup>. Especially, the first two decision rules are regarded as problematic in the literature (O'Connor, 2000). Typically, the Kaiser criterion overestimates the number of components. The reliability of the scree plot interpretations is regarded as low because the visual examination of the curve can include a high level of subjectivity. Consequently, parallel analysis and the MAP test should be considered as alternative (statistically based) procedures to determine the number of components. The decision on the number of factors to be extracted should be based on a comparison of different

---

<sup>4</sup> The scree plot is a graphical investigation of the components (x-axis) and their eigenvalues (y-axis). The cut-off point can be found at the number of components where the curve makes an elbow towards a less pronounced decline (i.e. there is only a small change in the eigenvalues from this point on).

<sup>5</sup> Parallel analysis chooses the number of components that accounts for more variance than the components derived from random data (Bühner, 2011, Ch.6). However, the accuracy of the parallel analysis decreases if the components are highly correlated. Moreover, an increasing sample size leads to the extraction of a higher number of components (number of items unchanged).

<sup>6</sup> According to O'Connor (2000, p.396), the MAP test chooses the number of components with the lowest "relative amounts of systematic and unsystematic variance remaining in a correlation matrix after the extraction of an increasing number of components".

procedures. Therefore, we apply the four different tests to the data and compare the results in order to determine the number of components.

The Kaiser criterion suggests extracting seven components, whereas the results of the original MAP test and Horn's parallel analysis indicate six components.<sup>7</sup> The solution with six components has no items that load high on multiple components and the number of items for each component is at least three. Moreover, we find that the reliability (i.e. Cronbach's alpha) of the components is in a similar range. An investigation of the scree plot also supports the decision to extract six components. For a summary of the test results, the reader is referred to the appendix.

### *Decision 3: Rotation method*

In order to be able to interpret components more easily, *orthogonal rotation methods* (i.e. latent components are assumed to be independent from each other), such as varimax rotation<sup>8</sup>, or *non-orthogonal (oblique) rotation methods* (i.e. latent components are assumed to be correlated), such as promax rotation<sup>9</sup>, can be applied. Based on the previous literature review (cf. section 2), we expect to find components that can be attributed to more general components. Therefore, we apply a non-orthogonal rotation method. Note that such a rotation method should also be applied if the components are found to be correlated (i.e.  $r > 0.1$ ).<sup>10</sup> For our case, we decide to apply promax rotation.

*Cronbach's alpha* is used to measure the reliability of the extracted factors. In general, a scale is seen as reliable if we find a Cronbach's alpha higher than 0.7 (i.e. the scale explains more than 50% of the variance, see e.g., Nunnally, 1978). For established scales, the Cronbach's

---

<sup>7</sup> The revised MAP test suggests extracting four components. However, the smallest average 4<sup>th</sup> power partial correlations ( $r^4$ ) are very similar for the 4<sup>th</sup>, 5<sup>th</sup> and 6<sup>th</sup> component. Therefore, we follow the results of the original MAP test which shows a clearer picture.

<sup>8</sup> Varimax rotation is the most commonly used orthogonal rotation method. It maximizes the variances of the squared factor loadings across variables for each factor, which minimizes the number of variables with high loadings. This increases the interpretability of the factors.

<sup>9</sup> By applying promax rotation, loadings from originally orthogonal factors are raised to the power of 2, 4 or 6. This reduces low as well as high loadings. Low or moderate loadings are shrunken to almost zero, while high loadings are kept more or less constant.

<sup>10</sup> We find most of the component combinations to be correlated ( $r > 0.1$ ). For details, see table A-2 in the appendix.

alpha should be higher than 0.8. On the other hand, in exploratory research a Cronbach's alpha above 0.6 is also considered acceptable.

### 3.2.2 Analysis of differences between groups of homeowners

For the PCA, we conduct a *Single-Factor Analysis of Variance (ANOVA)* or *t-test* to examine the question whether selected groups of homeowners in the sample differ with respect to their motivation to adopt a RHS.<sup>11</sup> This allows us to discuss the role of the identified components in relation to other variables. For this purpose, we check for significant effects stemming from different independent variables (i.e. factors) that characterize homeowners, including *home characteristics* (type, adopted RHS, energy standard, previous RHS, vintage class and size), *socio-demographic characteristics* (age, income, gender, education and occupation of the homeowner) as well as *spatial aspects* (location in an urban or rural area and a location in the eastern or western part respectively northern or southern part of Germany) on the variance of the factor scores of the extracted components (dependent variables). More specifically, we conducted the following three steps in our analysis:

#### *Step 1: Analysis if necessary assumptions for ANOVA and t-test are fulfilled*

For conducting an *ANOVA* or *t-test*, four assumptions have to be met. This includes that the data is (i) independent, (ii) metric, (iii) that the residuals are normally distributed and that (iv) the sizes of the variances of the populations in the sample are similar (homogeneity of variances). The assumption on the independence of data was met since we used a stratified random sampling technique in order to obtain a random selection of homeowners that recently adopted a RHS. Our data is metric since it stems from a standardized questionnaire. The assumption on the normal distribution of the residuals could be relaxed since we have a relatively large sample size ( $N=2440$ ) at our disposal. For testing the homogeneity of the variances, we used the Levene test.<sup>12</sup>

#### *Step 2: Analysis if populations in the sample differ significantly*

In this step, we investigate for different groups of homeowners (differentiated by selected variables) whether there are any significant differences in factor scores in the sample (i.e. subsamples differ significantly). For this purpose, we study the ANOVA respective *t-test* results.

---

<sup>11</sup> We conducted an ANOVA whenever more than two populations were in the sample. The *t-test* was used for cases with only two populations.

<sup>12</sup> If the Levene test indicates homogeneity of variances, we can interpret the ANOVA results. If there is no homogeneity of variances, we have to use the results from Welch's *F* test instead of the ANOVA results.

If we found statistically significant differences, the strength of the effect (i.e. practical significance) was examined by calculating the partial  $\eta^2$ .<sup>13</sup> We continued with step 3 if we detected that there are significant differences in the sample.

*Step 3: Analysis which populations in the sample differ significantly*

This step investigates which pairs of homeowners in the sample differ significantly. For this purpose, an appropriate *post-hoc* procedure has to be selected. The choice of the procedure depends on two aspects (Bühner and Ziegler, 2009, Ch.6). The first aspect addresses the structure of the variances (homogeneity or heterogeneity) and the second aspect the relation of the group sizes in the sample (equal or unequal sizes). If there is homogeneity of variances and there are groups with equal sizes in the sample, the Tukey test should be applied. If there is homogeneity of variances but groups with unequal sizes, either Gabriel's or Hochberg's GT2 procedure should be used. In our analysis, we applied the Hochberg *post-hoc* test procedure and the Games-Howell test. The latter should be used if the homogeneity of variances assumption is not met. The Games-Howell test also allows for unequal population sizes in the analysis. If we found statistical significant differences between pairs of populations in the sample, we investigated the practical significance of the differences (i.e. effect size) by calculating Cohen's *d*.<sup>14</sup> We used a significance level  $\alpha=.05$  for all subsequent analyses.

## 4 Results

### 4.1 Descriptive statistics

Table 2 shows the summary statistics for selected socio-demographic, home and spatial characteristics of the homeowners in our sample.

---

<sup>13</sup> The effect size partial  $\eta^2$  measures the strength of association between one or several predictors and a dependent variable in the sample. According to conventions in the literature, a partial  $\eta^2$  of .01 denotes a weak effect, a partial  $\eta^2$  of .06 a medium effect and a partial  $\eta^2$  of .14 a strong effect (Cohen, 1988, Ch.2).

<sup>14</sup> Cohen's *d* (*d*) 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, a *d* = .50 a moderate and a *d* = .80 a large effect. If the *d* is somewhere between two thresholds, then we have a small (moderate) to moderate (high) effect.

**Table 2:** Summary statistics of the home, socio-demographic and spatial characteristics of the sample ( $N = 2440$ )

<b>Adopted RHS</b>	Gas-fired condensing boiler with solar thermal support (GAS-ST)	28.4%
	Oil-fired condensing boiler with solar thermal support (OIL-ST)	10.5%
	Heat pump (HEAT-P)	36.5%
	Wood pellet-fired boiler (WOOD)	24.5%
<b>Type of the home</b>	Existing home	58.4%
	Newly built home	41.6%
<b>Size of the home</b>	Below 100 m <sup>2</sup>	4.0%
	100 to 149 m <sup>2</sup>	42.6%
	150 to 199 m <sup>2</sup>	30.2%
	200 to 249 m <sup>2</sup>	15.7%
	Above 250 m <sup>2</sup>	7.5%
<b>1-family home</b>	Yes	75.6%
	No	24.4%
<b>Energy standard</b>	Non-renovated home	21.6%
	Renovated home	25.0%
	Standard of an average newly built home	24.3%
	Low energy home	28.0%
	Passive house	1.1%
<b>Gender</b>	Female	16.6%
	Male	83.4%
<b>University degree</b>	Yes	64.5%
	No	35.5%
<b>Age of the homeowner</b>	35 and younger	14.8%
	35 – 39	13.4%
	40 – 44	14.4%
	45 – 49	14.5%
	50 – 54	11.4%
	55 – 59	10.8%
	60 – 64	8.3%
	65 and older	12.4%
<b>Monthly net income of the household</b>	Below €2000	13.3%
	€2000 to €2999	31.6%
	€3000 to €3999	27.1%
	€4000 to €4999	14.9%
	€5000 to €5999	6.6%
	Above €6000	6.4%
<b>South Germany</b>	Yes	40.0%
	No	60.0%
<b>East Germany</b>	Yes	12.1%
	No	87.9%
<b>Region with an urban or rural character</b>	Urban	64.2%
	Rural	35.8%

We included 25 variables in total in the PCA. The variables capture different motivational constructs of the adoption of a RHS and are based on 5-point Likert scales (1 = “completely disagree” – 5 = “completely agree” or 1 = “unimportant” - 5 = “very important”). 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 3 in the subsequent section 4.2.

## **4.2 Results of the analysis**

The principal component analysis (PCA) clusters the 25 variables around six components. This implies that the motivation to adopt a specific RHS out of a set of competing alternatives has six different dimensions.<sup>15</sup> Table 3 summarizes the results of the PCA.

---

<sup>15</sup> 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 variables are uncorrelated. The Cronbach's alphas of the extracted components are in a range between .818 and .627.

**Table 3: Statistics of the extracted components** ( $N = 2440$ )

No.	Component description	Cronbach's alpha	Item wording	Mean	S.E.	Loading	MSA	$h^2$
1	Cost aspects	.768	1 How important were the expected total costs for your decision?	2.67	1.298	<b>.796</b>	.836	.611
			2 How important was the current fuel price for your decision?	2.99	1.485	<b>.686</b>	.819	.557
			3 How important were expectations about the future fuel price for your decision?	3.09	1.514	<b>.674</b>	.801	.529
			4 How important were the maintenance costs for your decision?	2.05	1.259	<b>.673</b>	.837	.502
			5 How important was the expected payback period for your decision?	2.44	1.390	<b>.648</b>	.908	.422
			6 How important were the initial purchase costs for your decision?	3.22	1.222	<b>.537</b>	.870	.421
2	General attitude towards the RHS	.787	7 I can quickly accustom myself to the RHS.	4.27	.824	<b>.812</b>	.799	.648
			8 For me, the advantages outweigh the disadvantages of the RHS.	4.32	.804	<b>.749</b>	.823	.556
			9 If necessary, I would have no difficulty telling others about the RHS benefits.	3.78	.920	<b>.705</b>	.851	.533
			10 Using the RHS does not result in extra work.	3.78	1.005	<b>.698</b>	.833	.549
			11 Overall, I believe that the RHS is easy to use.	3.89	.883	<b>.673</b>	.843	.493
3	Government grant	.818	12 The BAFA grant made the installation of the RHS possible.	2.03	1.210	<b>.882</b>	.809	.750
			13 Without the BAFA grant, I would have chosen another RHS.	1.83	1.096	<b>.859</b>	.811	.682
			14 The possibility to receive a BAFA grant supported my decision in favor of the RHS.	3.44	1.296	<b>.786</b>	.878	.632
			15 How important were the purchase costs minus BAFA grant for your decision?	2.34	1.436	<b>.595</b>	.877	.629
4	Reactions to external threats	.682	16 I expected more independence from politically motivated supply crisis of oil and gas.	3.80	1.291	<b>.892</b>	.614	.789
			17 My intention was to become more independent from fluctuating energy prices.	3.87	1.113	<b>.884</b>	.631	.788
			18 My intention was to contribute to environmental protection.	4.13	.969	<b>.439</b>	.873	.273
5	Comfort considerations	.687	19 My intention was to have a low effort with fuel acquisition.	3.16	1.281	<b>.869</b>	.659	.747
			20 My intention was to have a RHS with little maintenance requirements.	3.23	1.208	<b>.846</b>	.656	.739
			21 I expected an improved utility value of my home by the installation of the RHS.	3.12	1.198	<b>.535</b>	.837	.356
6	Influence of peers	.627	22 Other people have influenced my decision in favor of this RHS.	2.40	1.220	<b>.801</b>	.688	.630
			23 The opinion of peers (e.g. friends or family) was important for my decision.	2.40	1.198	<b>.782</b>	.732	.609
			24 I knew a number of other people with a similar RHS.	2.20	1.084	<b>.731</b>	.759	.527
			25 By installing this RHS, I expected a positive response by others (e.g. recognition).	1.93	1.094	<b>.357</b>	.842	.293

In the following, we briefly describe and discuss the extracted components. Moreover, 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.

#### 4.2.1 Cost aspects (component 1)

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

The relevance of cost aspects is significantly influenced by the adopted RHS. A Welch  $F$ -test,  $F(3, 940.94) = 32.4$  ( $p < .01$ ), shows a statistically significant but weak effect ( $\eta^2 = .04$ ). In particular, *post-hoc* Games-Howell tests show that adopters of WOOD seem to significantly care more about cost aspects than adopters of GAS-ST ( $d = .55$ ), OIL-ST ( $d = .24$ ) and HEAT-P ( $d = .29$ ). Moreover, we find that adopters of OIL-ST ( $d = .26$ ) and HEAT-P ( $d = .30$ ) also consider cost aspects more than adopters of GAS-ST. Thus, the adoption of GAS-ST is relatively less motivated by cost aspects. In contrast, economic considerations have a relatively high relevance for adopters of WOOD. This reflects differences in e.g. the purchase and operating costs of these systems or differences in the average income of the adopters.

When it comes to differences stemming from certain characteristics of the home, we find that there are significant variances in the relevance of *cost aspects* between owners of existing and newly built homes. A  $t$ -test,  $t(2438) = -8.97$ , ( $p < .01$ , two-sided) shows a statistically significant but weak effect ( $d = .37$ ). This indicates that *cost aspects* play a less important role for the case of newly built 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 perceived as less relevant.

Moreover, the home's energy standard,  $F(4, 2300) = 22.49$  ( $p < .01$ ,  $\eta^2 = .04$ ), has also a significant impact on the relevance of *cost aspects*. In particular, *post-hoc* Hochberg tests show that there are statistically significant differences between a non-renovated home and a home with an energy standard of a typical newly built ( $d = .41$ ) respective a low-energy home ( $d = .28$ ). Likewise, we find statistically significant differences between a completely renovated home and a home with an energy standard of a typical newly built home ( $d = .49$ ) respectively a low-energy home ( $d = .35$ ). These results show that owners of 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, we find that the net dwelling area,  $F(4, 2422) = 7.36$  ( $p < .01$ ,  $\eta^2 = .01$ ), has a significant influence on *cost aspects*. In particular, *post-hoc* Hochberg tests find that costs are less relevant for a home with a size of 100 m<sup>2</sup> to 149 m<sup>2</sup> compared to a home with a size of 150 m<sup>2</sup> to 199 m<sup>2</sup> ( $d = -.24$ ) respectively 200 m<sup>2</sup> to 250 m<sup>2</sup> ( $d = -.21$ ). Thus, owners of 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 higher dimensioning.

#### 4.2.2 General attitude towards the RHS (component 2)

The second component describes the homeowners' *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.

For this component, we only find statistically significant variations between different income groups in the sample, Welch  $F(5, 636,703)=2.315$  ( $p < .05$ ,  $\eta^2 = .01$ ). For homeowners with an income in the range of €3000 to €3999, a Games-Howell test shows that the general attitude towards the RHS is a less important motivation than for homeowners with a higher income in the range of €5000 to €5999 ( $d = -.25$ ). Besides this, we find that there are no significant dissimilarities between other groups of homeowners. This shows that the general attitude towards the RHS has a similar effect on the motivation for almost all homeowners.

#### 4.2.3 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.

The influence of the capital grant on the adoption motivation differs by RHS,  $F(3, 2436) = 43.992$  ( $p < .01$ ,  $\eta^2 = .05$ ). Overall, we find that the BAFA grant is relatively less important for adopters of GAS-ST and HEAT-P, while adopters of WOOD and OIL-ST are relatively more motivated by the grant. In particular, *post-hoc* Hochberg tests show that adopters of WOOD seem to significantly care more about the capital grant than adopters of GAS-ST ( $d = .52$ ), OIL-ST ( $d = .33$ ) and HEAT-P ( $d = .56$ ). Moreover, we find that adopters of OIL-ST care more about the grant than adopters of GAS-ST ( $d = .20$ ) and HEAT-P ( $d = .23$ ). Reasons for that can be the relatively higher purchase costs of WOOD or the lower average income of adopters of OIL-ST and WOOD.

With respect to the characteristics of the home, we find that there are differences between owners of newly built and existing homes. A *t*-test,  $t(2234.73) = -11.34$  ( $p < .01$ , two-sided), shows a statistically significant effect ( $d = -.46$ ). Thus, we infer that the capital grant is less

relevant for owners of 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, we find that there are significant differences in the adoption motivation between the homes' energy standards,  $F(4, 2300) = 23.57$  ( $p < .01$ ,  $\eta^2 = .04$ ). The results of our analysis show that the BAFA grant is more relevant for homes with a lower energy standard. In particular, Hochberg tests find that the grant is more important for a non-renovated home compared to a home with an energy standard of a typical newly built ( $d = .41$ ) respective a low-energy home ( $d = .41$ ). The same applies for the case of a completely renovated home compared to a home with an energy standard of a typical newly built ( $d = .40$ ) respectively low-energy home ( $d = .41$ ).

We also find that the BAFA grant is less important for owners of single-family homes compared to owners of 2-family or row homes. A  $t$ -test,  $t(2429) = -5.59$  ( $p < .01$ , two-sided), shows a statistically significant effect ( $d = -.26$ ). Reasons for that can be the smaller dimensioning (and, thus, lower purchase costs) of RHS in single-family homes.

With respect to the socio-demographic variable income, we find that that there is a significant effect on the relevance of the BAFA grant for the adoption motivation,  $F(5, 2,228) = 7.30$  ( $p < .01$ ,  $\eta^2 = .02$ ). As expected, the grant is more important for homeowners with a lower income. In particular, Games-Howell tests show that the capital grant has a higher effect on adopters with an income below €2,000 compared to homeowners with an income in the range of €3,000 to €3,999 ( $d = .25$ ), €5,000 to €5,999 ( $d = .38$ ) or an income of €6,000 and above ( $d = .52$ ). Moreover, we find that homeowners with an income of more than €6,000 are less motivated by the BAFA grant than homeowners with a lower income in the range of €2,000 to €2,999 ( $d = -.38$ ), €3,000 to €3,999 ( $d = -.30$ ) and €4,000 to €4,999 ( $d = -.33$ ), respectively.

#### **4.2.4 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.

We find that the RHS adopted has a strong impact on the relevance of the component *reactions to external threats* on the adoption motivation. A Welch  $F$ -test,  $F(3, 917.21) = 337.10$  ( $p < .01$ ), shows a statistically significant and large effect ( $\eta^2 = .32$ ). Games-Howell tests show

that this component, in particular, is of less relevance for adopters of GAS-ST compared to adopters of HEAT-P ( $d = -1.25$ ) respectively WOOD ( $d = -1.54$ ). We get similar results for OIL-ST compared to adopters of HEAT-P ( $d = -1.15$ ) respectively WOOD ( $d = -1.54$ ). Finally, we find that the component *reactions to external threats* has a higher relevance for adopters of WOOD compared to HEAT-P ( $d = .37$ ). These findings also reflect the type of fuel used by the system concerned. As expected, homeowners that use the fossil fuels natural gas or oil for heating are less motivated by external threats than homeowners that use the renewable energy source wood pellets as a fuel.

With respect to the home characteristic dwelling size, we find a significant impact of differences in size on the relevance of this component. An  $F$ -test,  $F(4, 2422) = 4.11$  ( $p < .01$ ), shows a statistically significant effect ( $\eta^2 = .01$ ). Hochberg tests find that owners of homes with a dwelling size in the range of 100 m<sup>2</sup> to 149 m<sup>2</sup> are less motivated by external threats than owners with a home of a size in the range of 200 m<sup>2</sup> to 249 m<sup>2</sup> ( $d = -.22$ ). 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.

#### **4.2.5 Comfort considerations (component 5)**

Component 5 includes *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.

Our results show that the relevance of the component *comfort considerations* differs by adopted RHS. An  $F$ -test,  $F(3, 2436) = 75.05$  ( $p < .01$ ), shows a significant effect ( $\eta^2 = .09$ ). Hochberg tests show that adopters of WOOD are less motivated by comfort considerations than adopters of GAS-ST ( $d = -.60$ ) and HEAT-P ( $d = -.76$ ). For adopters of OIL-ST, we find a lower relevance of this component compared to homeowners that adopted GAS-ST ( $d = -.23$ ) or HEAT-P ( $d = -.40$ ). However, adopters of OIL-ST are more motivated by comfort considerations than adopters of WOOD ( $d = .37$ ). Our findings reflect the ease of use that can be linked to each of these RHS, i.e. WOOD and OIL-ST require relatively more effort when operating the RHS than both GAS-ST and HEAT-P.

We find that owners of newly built homes are more motivated by *comfort considerations* than owners of existing homes,  $t(2438) = 4.74$  ( $p < .01$ , two-sided,  $d = .20$ ). A possible explanation is that owners of existing homes are already used to the comfort level of their home and, thus, care less about this component.

For the energy standard of the home, we find a significant impact on the relevance of *comfort considerations* on the adoption motivation,  $F(4, 2300) = 4.84$  ( $p < .01$ ,  $\eta^2 = .01$ ). In particular, Hochberg tests reveal that owners of a non-renovated home are less motivated by comfort considerations than owners of a home with an energy standard of a newly built ( $d = -.20$ ) or a low-energy home ( $d = -.24$ ). 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, owners of such homes are probably already used to a higher comfort related to the home.

The variable income has a significant impact on *comfort considerations*,  $F(5, 2228) = 10.50$  ( $p < .01$ ,  $\eta^2 = .02$ ). This component is more important for homeowners with an income below €2,000 compared to higher income classes. In particular, *post-hoc* Hochberg tests reveal that homeowners with an income below €2,000 are more motivated by *comfort considerations* than homeowners in higher income classes including €2,000 to €2,999 ( $d = .23$ ), €3,000 to €3,999 ( $d = .31$ ), €4,000 to €4,999 ( $d = .50$ ), €5,000 to €5,999 ( $d = .48$ ) respectively €6,000 or higher ( $d = .46$ ). We find a similar significant effect when comparing homeowners with an income in the range of €2,000 to €2,999 with homeowners with an income of €4,000 to €4,999 ( $d = .28$ ). A possible reason can be that homeowners with an income of below €2,000 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 owners with a higher income.

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

## **5 Discussion and conclusions**

Space heating demand represents the major fraction of the overall energy demand for residential purposes in Germany. Thus, it is the main source of CO<sub>2</sub> emissions in the residential buildings sector. Therefore, in particular against the background of climate change as well as considerations related to the security of energy supply and increasing energy prices, under-

standing the adoption of innovative (i.e. energy-efficient and renewable energy sources-based) RHS by private homeowners is of high relevance. The purpose of this research was to empirically investigate the dimensionality of the homeowners' RHS adoption motivation. Until now, most studies in this field have used stated preferences data on hypothetical RHS adoption decisions. Only relatively little research has so far empirically analyzed the homeowners RHS adoption motivation by means of *ex-post* data (i.e. data on real adoption decisions) in a systematic manner. Therefore, we make a significant empirical contribution towards a better understanding of the RHS adoption motivation at the level of the individual homeowner in Germany. However, there are also some limitations of our research. First, our study does not cover all types and possible combinations of RHS, i.e. we only consider the four most commonly adopted systems (partly) based on renewable energies. Second, the focus of our research is on homeowners that have taken an RHS adoption decision only very recently (2009-2010). Therefore, our results are only valid for the period of time when the survey was conducted. Third, we only consider the RHS adoption motivation. However, 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). Finally, the survey covered only motivational factors that were identified from the literature.

Our research shows the dimensionality of the homeowners' motivation to adopt a certain RHS out of a set of competing alternatives. We are able to show that the extracted components reflect certain elements of theories on individual decision-making (cf. section 2). Our research reveals that elements related to the individual attitude towards the RHS as well as subjective norms (e.g. influence of peers) influence the adoption motivation. Moreover, our findings confirm that the RHS adoption motivation has not only the character of rational decision-making but has also an emotional (i.e. psychological and cognitive) nature.

Dimensions that are characterized by rational decision-making have 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.

Furthermore, there are differences in the RHS adoption motivation between selected groups of homeowners in our sample. In particular, 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. For the effect of socio-demographic characteristics, we only find some evidence. We find a weak influence of income on the components *general attitude towards the RHS*, *government grant* and *comfort considerations*. 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).

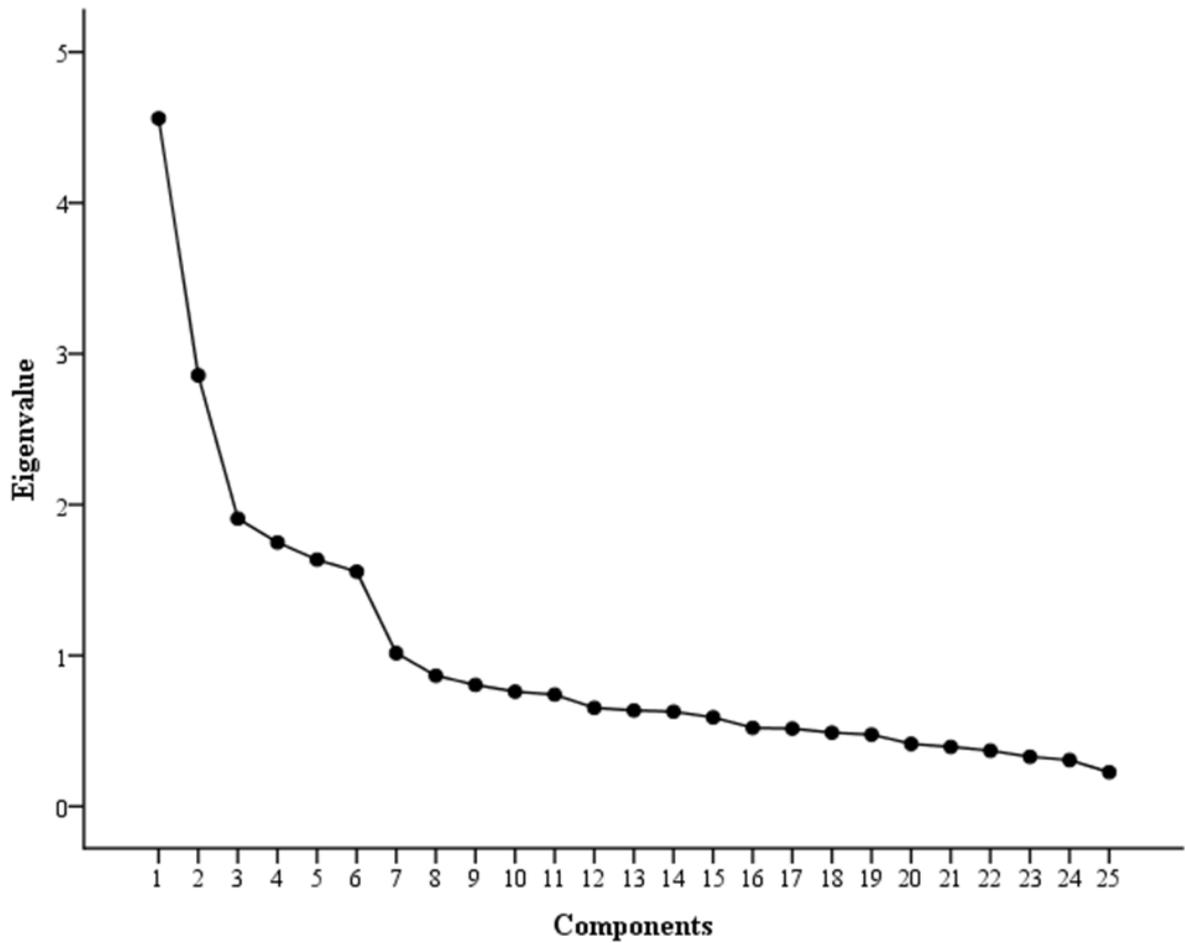
A number of conclusions can be derived from our research. First, we can draw some economic implications from our research. The results show that the impact of the BAFA grant on the RHS adoption motivation differs between groups of homeowners. Rather than distributing the financial resources available in a relatively non-selective way (i.e. also to homeowners where the grant appears to have limited relevance for the adoption motivation), the grant should take the heterogeneity of homeowners into account. Therefore, the amount of the capital grant should be determined by certain RHS (e.g. wood pellet-fired boilers), specific home characteristics or socio-demographic characteristics, such as the homeowners’ income level. 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 the design of policy instruments or marketing strategies of RHS manufacturers. For policymakers, this means that energy and climate policy instruments targeting the residential buildings sectors in general, and innovative RHS in particular, should explicitly address the different dimensions of the homeowners’ RHS adoption motivation. This requires a balanced bundle of targeted policy instruments. On the one hand, such instruments should 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 should 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. Finally, our results have also managerial implications. The identified dimensions offer different starting points for marketing campaigns of RHS manufacturers.

## 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 partialled out components	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

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



**Figure A-1:** Factor extraction according to scree plot (6 components)

**Table A-2:** Correlation matrix for the extracted components

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

## 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.
- 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](http://www.bdew.de/bdew.nsf/id/DE_Energiemarkt_Deutschland_-_Sommer_2009/$file/09%2011%2009%20Energiemarkt_2009.pdf) [April 30, 2012].
- Braun, F. (2010), Determinants of households' space heating type: A discrete choice analysis for German households, *Energy Policy*, 38(10), 5493-5503.
- Bühner, M. and Ziegler, M. (2009), *Statistik für Psychologen und Sozialwissenschaftler*, München: Pearson Studium.
- Bühner, M. (2011), *Einführung in die Test und Fragebogenkonstruktion*, 3<sup>rd</sup> Edition, München: Pearson Studium.
- Claudy, M.C., Michelsen, C., 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*, 2. Aufl., 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., 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](http://www.erneuerbare-energien.de/files/english/pdf/application/pdf/ee_waermeg_en.pdf) [April 30, 2012].
- Faiers, A. and Neame, C. (2007), Consumer attitudes towards domestic solar power systems, *Energy Policy*, 34(14), 1797-1806.
- 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.
- Gatersleben, B., Steg, L. and Vlek, C. (2002), Measurement and determinants of environmentally significant behavior, *Environment and Behavior*, 34(3), 335-362.
- 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.
- Labay, D. and Kinnear, T. (1981), Exploring the consumer decision process in the adoption of solar energy systems, *The Journal of Consumer Research*, 8(3), 271-278.
- 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., 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. and 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. Available online: [http://papers.ssrn.com/sol3/papers.cfm?abstract\\_id=1898688](http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1898688).
- Miller, K. (2005), *Communications theories: perspectives, processes, and contexts*, New York, McGraw-Hill.
- 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* (2<sup>nd</sup> 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.

- Pollard, M., Kalafatis, S. P., East, R. and Tsogas, M. H. (1999), Green marketing and Ajzen's theory of planned behavior: a cross-market examination, *Journal of Consumer Marketing*, 16(5), 441-460.
- Rogers, E. (2003), *Diffusion of Innovations*, 5<sup>th</sup> Ed., New York: The Free Press.
- Rouvinen, S. and Matero, J. (2011), Stated Preferences of Finnish Homeowners for Residential Heating Systems: discrete choice experiment. Paper presented at *Project Bioenergy Markets – Workshop Oslo*, 24-25 October 2011.
- Sanhi, A. (1994), Incorporating perceptions of financial control in purchase prediction: An empirical examination of the theory of planned behavior, *Advances in Consumer Research*, 21, 442-448.
- 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.
- 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., 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.
- Völlnik, T., Meertens, R. and Midden, C.J.H. (2002), Innovating “diffusion of innovation” theory: innovation characteristics and the intention of utility companies to adopt energy conservation interventions, *Journal of Environmental Psychology*, 22(4), 333-344.
- 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



## List of FCN Working Papers

### 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.
- 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.
- 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.

## 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., 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.

Rohlf 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.

Rohlf 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.
- 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.
- 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., Ribaud 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](http://www.eonerc.rwth-aachen.de/fcn)) and the SSRN Website ([www.ssrn.com](http://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](mailto: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 6, 52074 Aachen, Germany.