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Homeowners' Preferences for Adopting Residential Heating Systems: A Discrete Choice Analysis for Germany

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Abstract

Space heating accounts for a large fraction of the primary energy consumption and CO_2 emissions of residential buildings. Besides targeting the insulation standard, residential heating systems (RHS) offer the potential to reduce energy demand for space heating. Therefore, understanding the determinants of the RHS adoption decision becomes increasingly important. In this paper, we analyze the influence of preferences about RHS-specific attributes on the homeowners' adoption decision. Moreover, we control for the influence of socio-demographic, home and spatial characteristics. To this end, we specify the discrete appliance choice by a multinomial logit model and apply it to representative survey data for Germany. Our findings show that there are different drivers for the adoption of RHS in newly built and existing 1- and 2-family homes, and that the importance of key drivers also differs across groups of homeowners and RHS, respectively. First, we find that adopters of a gas- and oil-fired condensing boiler with solar thermal support have a strong preference for energy savings, while adopters of a heat pump or wood pellet-fired boiler prefer being more independent from fossil fuels. Second, we find that owners of existing homes have less scope for preferences in the RHS adoption decision. The decision to replace a RHS in an existing home is rather driven by socio-demographic, home and spatial characteristics. Third, our findings are quite contrary for newly built homes. Here, preferences about RHS specific attributes are found to be highly relevant, while there is less evidence for an influence of socio-demographic, home and spatial characteristics on the adoption decision.

Key words: Technology adoption; Consumer behavior; residential heating systems; space heating; discrete choice

JEL Classification Nos.: D12, 033, Q41, R22

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1 Introduction

Residential space heating accounts for a large fraction of the private households' overall energy demand. In Germany, about 71.6% of the private households' final energy demand in the year 2008 can be attributed to this field of energy use (AGBE, 2011). Since oil and natural gas are predominant in fueling residential heating systems (RHS), almost 83% of the CO_2 emissions from the residential sector come from space heating (Destatis, 2010a).[1] This corresponds to about 25.7% of the total CO_2 emissions in 2008 (Destatis, 2010b). Hence, residential space heating is strongly connected to the issues of global warming, security of energy supply, and increasing energy prices. At the same time, the technical and economic potentials for energy and CO_2 savings are huge in the residential building sector. According to Beyer et al. (2011), the implementation of additional policy instruments in the buildings sector could save up to 18 million tons of CO_2 in the year 2020.[2] Consequently, one of the main aims of the long-term energy plan (*Energiekonzept*) of the German government announced in 2010 is to reduce the primary energy requirement of the residential building stock by at least 80% by 2050 and to cover the remaining energy requirements with renewables (Bundesregierung, 2010). Different retrofit measures and the installation of renewables-based RHS in newly built and existing homes shall contribute to reaching this goal. However, this implies targeting a heterogeneous group of homeowners that differ e.g. with respect to their financial possibilities, the characteristics of their homes or their preferences regarding RHS adoption. Moreover, the adoption decision is important because it concerns highly durable goods. Thus, such a decision fixes the potential CO_2 emissions from a home over at least the next 20 years, assuming that there are no changes in behavior or the intensity of use. Consequently, it is of high relevance to gain a deeper understanding of the homeowners' decision-making process.

In this paper, we investigate how homeowners in Germany decide in favor of a certain RHS. Therefore, the following questions guide our research: What determines the RHS adoption decision? What is the influence of preferences about RHS-specific attributes, socio-demographic, home or spatial (i.e. location in a certain geographical area) characteristics on the probability to adopt a certain RHS? Are there any significant differences between owners of existing and newly built homes?

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[1] In 2008, about 13.3% of the final residential energy demand was used for hot water generation. Space heating and hot water generation accounted for 84.9% of the private households' final energy demand (AGEB, 2011).

[2] This refers to the direct CO_2 emissions of the entire buildings sector (including residential, commercial and public buildings). In 2010, total CO_2 emissions of the buildings sector were at 162 million tons.

For the purpose of our research, we carried out a representative and self-administered national survey among randomly selected owners of existing or newly built 1- and 2-family homes in Germany.[3] 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 (partly) based on renewable energy sources. Hereby, we gathered a unique set of micro data on the RHS adoption decision. We then apply a discrete choice model on a combination of revealed and stated preferences data. This allows separating the influence of different factors on the probability to adopt a certain RHS. 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. We assume that different factors influence the individual adoption decision, and that preferences about RHS-specific attributes, socio-demographic characteristics of the homeowner, home attributes and spatial characteristics differ among individual households.

Research that applies a discrete choice framework on the determinants of residential energy behavior, such as appliance choice, was carried out by Dubin and McFadden (1984), Vaage (2000), Liao and Chang (2002), Mansur et al. (2008) and Goto et al. (2011), among others. Braun (2010) analyzed the determinants of applying different space heating types of German households. However, all these studies are based on appliance ownership data and do not use any data on the actual adoption decision itself. Only few studies exist up to now that use stated preferences data on a hypothetical RHS adoption decision, such as Achtnicht (2010), who uses data from a choice experiment. To the best of our knowledge, no research has so far empirically examined the homeowners' actual RHS adoption decisions by means of a combination of stated and revealed preferences data in Germany. Therefore, we make a significant empirical contribution towards a better understanding of the adoption of RHS at the level of the individual decision-maker. Moreover, a more detailed knowledge of the underlying preferences and determinants behind the adoption decision can also contribute to a better design of policy instruments targeting RHS and marketing strategies by RHS manufacturers. Insights

[3] According to IWU (2007), about 60% of the overall living space can be attributed to 1- and 2-family homes (including terraced houses). In 2009, there were about 14,957,646 1- and 2-family homes in Germany (Destatis, 2011b). These homes are usually detached or semidetached. A 1-family home comprises one residential unit and is normally occupied by a single family. 2-family homes cover two residential units (i.e. two apartments) and the RHS is usually shared. Multi-family homes comprise more than two residential units.

from this study for Germany can also be transferred to other countries aiming at reducing the CO_2 emissions from residential space heating.

The remainder of this paper is structured as follows: Section 2 summarizes the recent situation regarding RHS in Germany. In Section 3, we give an overview of the literature on energy appliance choice with a particular focus on RHS. Section 4 describes the survey procedure and data used. In section 5, we introduce the multinomial logit (MNL) model applied. Section 6 presents and discusses the results of the analysis. Finally, section 7 contains some conclusions and provides recommendations for further research, policy-makers and business.

2 Residential heating systems in Germany

2.1 Policy framework

As part of the Integrated Energy and Climate Program announced in 2007, the German government has set the goal of increasing the share of renewable heat supply from some 6% in 2007 to 14% in the year 2020 (see BMU, 2007, for details). A number of policy instruments have been implemented for reaching this target. From January 1, 2009, onwards, the "Act on the Promotion of Renewable Energies in the Heat Sector" obliges owners of newly built homes to use a minimum share of heat from renewable sources, such as solar, biomass or geothermal heat, to cover their energy requirements for space heating and hot water generation (BMU, 2008).[4] The Market Incentive Program (MAP) implemented by BAFA offers financial support (BAFA grants) for homeowners installing a RHS.[5] Among homeowners, the MAP is a very popular financial support program.[6] To be eligible for BAFA grants, the RHS has to be (partly) based on renewable energies and to fulfill certain energy efficiency standards (BMU, 2008). In 2009 and 2010, the MAP was subject to frequent changes, including cutbacks in the size of capital grants in particular for newly built homes (dates of revisions in the directive:

[4] At least 15% have to be covered by solar thermal collectors or a minimum of 50% has to stem either from a biomass-fired RHS or a heat pump. This can be circumvented e.g. by increasing the overall energy efficiency of the home by at least 15% (compared to the required minimum standard) or the usage of district heating.

[5] According to BMU (2010), the MAP had a budget of about €375,000,000 and approximately 253,000 capital grants for solar thermal collectors, heat pumps and biomass-based RHS were awarded in 2009 (note that grant recipients receive more than one grant when combining solar thermal collectors with another RHS).

[6] A high share of homeowners installing a new RHS applies for BAFA grants. Langniß et al. (2010) estimate that about 302,000 RHS (partly) based on renewable energies were installed in 2009. The MAP covered 74% of these installations. The total number of installed RHS was at 638,000 in 2009 (BDH, 2010). These figures include also multi-family homes, and solar thermal collectors, usually combined with another RHS.

1/3/2009, 22/2/2010, 12/7/2010) and a temporary budget freeze (3/5/2010 – 11/7/2010). Since July 12, 2010, only owners of existing homes are eligible for BAFA grants. For the period between March 1, 2009, and February 21, 2010, table 1 shows the approximate grant size, the average purchase and installation costs according to IE Leipzig (2009) and the resulting funding quota for selected RHS in a newly built and an existing 1-family home.[7]

Table 1: Average purchase and installation costs, approximate BAFA grant sizes and funding quota in 2009

Type of RHS	Type of home	Purpose of solar thermal support	BAFA grant*	Level of capital grant [Euro]	Average purchase and installation costs in 2009 [Euro]	Funding quota [%]
Gas-fired condensing boiler with solar thermal support	new	hot water	*1*	307	9,817	3.1
		heating	*1*	945	13,817	6.8
	existing	hot water	*1, 2*	785	9,817	8.0
		heating	*1, 2*	2010	13,817	14.6
Oil-fired condensing boiler with solar thermal support	new	hot water	*1*	307	11,840	2.6
		heating	*1*	945	15,840	6.0
	existing	hot water	*1, 2*	785	12,197	6.4
		heating	*1, 2*	2010	16,197	12.4
Heat pump ground source / air source	new	no solar	*3*	2,000 / 850	16,303 / 11,781	12.3 / 7.2
		hot water	*1, 3, 5*	3,057 / 1,907	20,303 / 15,781	15.1 / 12.1
		heating	*1, 3, 5*	3,695 / 2,545	24,303 / 19,781	15.2 / 12.9
	existing	no solar	*3*	3,000 / 1,500	22,848 / 13,328	13.1 / 11.3
		hot water	*1, 3, 5*	4,160 / 2,660	26,848 / 17,328	15.5 / 15.4
		heating	*1, 3, 5*	5,010 / 3,510	30,848 / 21,328	16.2 / 16.5
Wood pellet-fired boiler	new	no solar	*4*	1,875	15,827	11.8
		hot water	*1, 4, 5*	2,932	18,326	16.0
		heating	*1, 4, 5*	3,570	20,825	17.1
	existing	no solar	*4*	2,500	17,017	14.7
		hot water	*1, 4, 5*	3,660	19,575	18.7
		heating	*1, 4, 5*	4,510	22,133	20.4

***** 1 = *Basisförderung Solar*, 2 = *Kesseltauschbonus*, 3 = *Wärmepumpe*, 4 = *Basisförderung Biomasse*, 5 = *Regenerativer Kombinationsbonus*; Size of solar thermal collector for hot water generation (heating support): 6 m^2 (12 m^2)
Sources: IE Leipzig (2009), MAP (2009), own calculations.

[7] Please note that these are average purchase and installation costs that may vary according to the characteristics of the home, such as the energy standard or the size. In cases where IE Leipzig (2009) provided no cost figures for adding solar thermal collectors to a RHS, we assumed a markup of €4,000 (€8,000) for hot water generation (heating support). Further, we calculated the level of financial support by taking into account the grants for solar thermal collectors (*Basisförderung Solar*), heat pumps (*Basisförderung Wärmepumpe*) and wood pellet-fired boilers (*Basisförderung Biomasse*). Moreover, we considered grants for combining solar thermal collectors with a heat pump respectively by a wood pellet-fired boiler in existing and newly built homes (*Regenerativer Kombinationsbonus*) or with a condensing boiler in existing homes (*Kesseltauschbonus*). Other BAFA grants (e.g. *Innovationsbonus* or *Effizienzbonus*) and financial support from other sources were not taken into account.

Furthermore, dedicated programs of the government-owned development bank KfW, such as the Energy-Efficient Refurbishment Program, offer low interest loans and grants connected to the renewal or initial installation of an innovative RHS. Moreover, there are grants for on-site consulting services supporting the energy retrofit of a home. The Combined-Heat-and-Power Production (CHP) Act supports micro-cogeneration / micro-CHP by means of a guaranteed feed-in tariff. There are also several similar financial incentive and information programs targeting RHS on the level of the federal states or the communities. Moreover, a number of utilities offer financial incentives targeting RHS.[8]

The long-term energy plan of the German government introduced in 2010 aims at reducing the primary energy requirement of the residential buildings stock by at least 80% until 2050 (Bundesregierung, 2010).[9] Renewable energy sources are supposed to cover the remaining energy requirements. In order to achieve this goal, a number of new policy instruments has to be implemented in the coming years.

2.2 Market data

According to BDH (2010), almost 60% of the RHS stock installed in residential buildings (including 1- and 2- family as well as multi-family homes) consisted of gas-fired boilers in 2008.[10] About 34.8% of the installed RHS were oil-fired (share of oil-fired condensing boilers: 1.1%). Thus, fossil fuel-fired boilers accounted for almost 95% of the installed RHS stock. Biomass-fired boilers represented 3.9% and heat pumps 1.7%.

However, the situation looks different when annual sales data are considered. We can observe a marked decline in the shares of gas- and oil-fired low temperature boilers over time. Gas- and oil-fired condensing boilers gained increasing market shares in annual sales in the period between 1998 and 2009. More recently, other innovative RHS, such as the electric heat pump and biomass-fired boilers, started to penetrate the market in larger numbers and to successful-

[8] For example, some utilities offer financial support for replacing an old oil-fired RHS by a gas-fired RHS or a heat pump. These incentive programs are usually used as marketing tools for increasing customer loyalty or to attract new customers. On the level of the federal states or the communities, programs targeting RHS are usually implemented for reaching certain CO_2 reduction or energy-saving targets on the regional or local level. Typically, such programs have a limited budget or application period.

[9] The energy plan does not explicitly state any base year for the 80% reduction target. In discussions among experts, an 80% reduction compared to current standards is usually used as a reference.

[10] Gas-fired condensing boilers had a share of 15.2%, while gas-fired low temperature or combi boilers (providing heat and hot water directly from the boiler with no storage tank) accounted for 44.4%.

ly compete for shares. Solar thermal collectors usually supplement a RHS. Due to regulatory requirements and financial incentives, also the number of installed solar thermal systems increased in recent years (BSW, 2011).[11] The diffusion of the heat pump and the biomass-fired boiler (mainly based on wood pellets) took off recently, while the diffusion process of the condensing boiler is more mature. Variations in the annual sales of the biomass-fired boiler can be explained by e.g. changes in governmental support or variations in the price of wood pellets. Over the years, the total number of annually installed RHS declined from 920,000 in 1998 to 638,000 in 2009 (BDH, 2009; 2010). The main reason for this can be found in the decrease of the annual number of newly built homes.[12] Figure 1 shows the annual market shares (covering installations in all types of residential buildings) of the most common RHS.

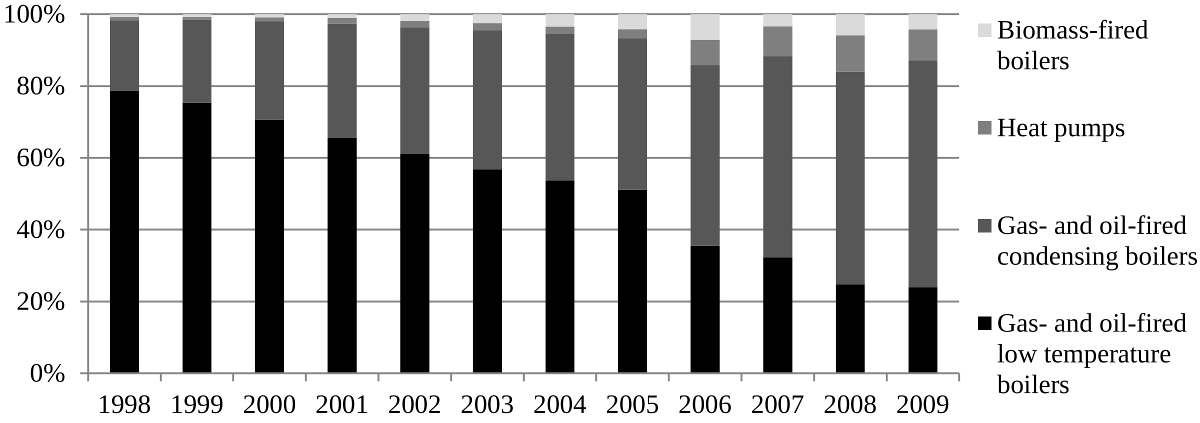

Figure 1: Annual market shares (%) of newly installed RHS in Germany between 1998 and 2008
Source: Own illustration, based on data from BDH (2009) and BDH (2010)

There are not only differences in the total annual sales shares of RHS but also between the federal states. According to data from *Biomasseatlas* (2011), most wood pellet-fired boilers are installed in Southern Germany (almost 60% in Bavaria and Baden-Wuerttemberg). Data on the total number of installed heat pumps show that most of these systems (in relation to the number of 1- and 2-family homes) have been installed in Bavaria and North Rhine-Westphalia as well as in the eastern federal states Saxony, Thuringia and Brandenburg (AEE, 2010). Furthermore, more than 50% of the entire solar thermal collectors had been installed in Baden-Wuerttemberg and Bavaria until 2008 (cf., AEE, 2010). A possible explanation for this

[11] According to the German Solar Industry Association (BSW, 2009), about 265,000 solar thermal collectors covering 2.3 million m^2 had been installed until 1999. In 2010, there were already about 1,590,000 solar thermal systems with a total surface area of 14 million m^2.

[12] According to Destatis (2011a), 220,611 1- and 2- family homes were constructed in 1998. This number decreased steadily in the following years. In 2009, there were only 83,898 newly built 1-2 family homes.

North-South divide is due the fact that solar irradiation is higher in the Southern federal states, which increases the efficiency and cost effectiveness of solar radiators.

3 Literature review

The economic literature contains a number of examples on energy (i.e. fuel type) and energy appliance choice in general and the choice of RHS in particular. In many cases, these studies apply logit models (i.e. multinomial, conditional, mixed or nested logit models) for analyzing the choice decision of consumers. For Germany, however, such research is relatively rare.

Several studies employed a two-stage modeling approach for the choice of energy appliances by households and the resulting energy consumption (i.e. discrete-continuous choice approach).[13] For the appliance choice, these studies apply logit models mostly on data from large household surveys on the national level (e.g. German Socio-Economic Panel - SOEP). Typically, the choice (in terms of availability or ownership) relies on household-specific data, such as socio-demographic characteristics (e.g. age of the household head, household income or number of household members), attributes of the home (e.g. vintage class, type, size or energy standard), costs (e.g. purchase or operational costs) or spatial variables (e.g. location in a certain geographic area, administrative unit, rural region or certain climate zone). The results show that most socio-demographic variables significantly influence the choice of the appliance. Some studies find home characteristics to be even more important than socio-demographic aspects. Finally, spatial characteristics are also found to be key determinants. Preferences about RHS-specific attributes are usually not included.

Pioneers in this field are Dubin and McFadden (1984) on heating appliance choice by U.S. households. Dubin (1986) extended this research to space and water heating systems. Furthermore, a number of more recent studies used a discrete or discrete-continuous choice approach similar to Dubin and McFadden (1984). Also for the U.S., Liao and Chang (2002) examined the choice of energy for space and water heating by elderly people and Mansur et al. (2008) analyzed fuel choice and fuel consumption. For Norway, Nesbakken (1999) and Vaage (2000) studied the choice of a heating technology and the resulting continuous energy demand. An example for research focusing on the appliance choice only is Goto et al. (2011) on the choice of different types of ecologically efficient water heaters in Japan. Moreover, for Germany, Mills and Schleich (2009) investigated the adoption of residential solar thermal technologies for space and water heating. Braun (2010) analyzed the determinants of the type

[13] The conditional energy demand is estimated with a continuous regression approach.

of RHS applied by a household (i.e. the adoption decision itself was not addressed) for a sample of homeowners only and a sample including all households (i.e. owners and tenants) based on SOEP data.

A number of studies apply alternative methodologies for investigating energy appliance choice, fuel type choice and fuel demand on survey data. For example, Matsukawa and Ito (1998) estimated a probabilistic discrete choice model of residential air conditioners for Japan. Fernandez (2001) studied the replacement of home energy appliances in the U.S. by estimating a duration model. Sardianou (2008) analyzed the determinants for space heating in Greece by means of different regression techniques (including probit). For Germany, Schuler et al. (2000) investigated the influence of socio-demographic variables on the consumption behavior regarding different types of fuel for residential heating and given building features. Rehdanz (2007) studied the conditional energy demand for space and water heating in Germany (i.e. RHS choice was not explicitly considered) by applying SOEP data. Further research by Rehdanz and Stöwhase (2008) examined the energy consumption behavior of welfare and non-welfare recipients. Madlener and Hauertmann (2011) investigate the elasticity of the demand for residential space heating with SOEP data.

Another strand of the literature investigates the willingness to pay (WTP) for certain energy appliances by using stated preferences data from choice experiments or surveys designed for the specific research question. In this research, the focus is on the consumers' preferences about appliance-specific attributes (e.g. comfort, environmental considerations, energy supply security, recommendation by others, cost aspects or the influence of a financial grant). In particular, the results show that heterogeneity of preferences about the energy savings potential, environmental benefits, comfort considerations, compatibility with daily routines and habits or cost aspects influence energy and energy appliance choice.

For example, Banfi et al. (2008) investigated the WTP for energy-saving measures in Swiss residential buildings by means of a choice experiment. Scarpa and Willis (2010) studied the WTP of British households for micro-generation technologies (including, among others, solar thermal collectors, heat pumps, biomass boilers and micro-CHP). Achtnicht (2010) carried out a choice experiment on the WTP for energy retrofits in existing homes among homeowners in Germany. Claudy et al. (2011) analyzed 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.

The explanatory variables used in the choice models discussed above can be classified into (1) socio-demographic, (2) home, and (3) spatial characteristics as well as (4) preferences about RHS-specific attributes. Moreover, the influence of these variables on the choice decision varies significantly across technologies. Most studies, and in particular research that draws on revealed preferences respective ownership data, include the first three categories in their models. Research that explicitly considers preferences about RHS-specific attributes is typically based on choice experiments (i.e. stated preferences data). To the best of our knowledge, no research to date has drawn on both revealed and stated preferences data in order to investigate the RHS adoption decision. Table 2 gives an overview of the most frequently used explanatory variables in the reviewed studies on energy and energy appliance choice.

Table 2: Overview of most frequently used explanatory variables in the literature (own illustration)

Socio-demographic characteristics	Home characteristics	Spatial characteristics	RHS-specific attributes
• Age • Household income • Educational status • Family size • Children presence	• Floor size • Vintage class • Home type • Available infrastructure	• Administrative unit • Urban / rural • Climate zone • East / West Germany • North / South Germany	• Environmental benefits • Comfort • Energy supply security • Recommendation • Cost aspects • Financial grant

4 Survey procedure and data description

4.1 Survey development and implementation

For the development, pretest and implementation of the questionnaire survey we followed the Tailored Design Method proposed by Dillman (2007). In a stage I, we made an extensive review of the relevant literature, and collected items to be included in the questionnaire. A conceptual model on the homeowners' RHS adoption decision proposed by Michelsen and Madlener (2010) guided the selection of items. Stage II included a review of the draft questionnaire by experts from different academic fields. Based on this, the questionnaire was revised and further developed. In stage III, we carried out a cognitive pretest of the questionnaire among experts in the field of survey development on the one hand, and homeowners who have recently installed a new RHS on the other hand. This was done in order to detect possible misinterpretations of the items. Stage IV comprised a pre-study among owners of 1- and 2-family homes in Germany (*n*=300). The pre-study revealed some first indications on the response rate (about 41%), missing values or distribution of the item answers. Lastly, we finalized the questionnaire based on the insights from the pre-study.

In the main study, we mailed the questionnaires to 5000 randomly selected homeowners who had received a BAFA grant for installing a new RHS between January 2009 and August 2010 (cf. section 2.1). Based on our instructions, BAFA drew a disproportional, stratified random sample out of four different groups.[14] The goal was to collect a representative database for existing and newly built 1- and 2-family homes in which a RHS adoption decision was taken in the last two years. Moreover, a stratified random sample allows a better comparison of different groups. Table 3 illustrates the groups in our sample.

Table 3: Description of the different groups in the stratified sample (own illustration)

	Name of BAFA grant	**RHS type**	**Home type**	**Sample size *n***
Group 1	*Kesseltauschbonus*	Gas- or oil-fired condensing boiler with solar thermal support	Existing 1- or 2-family home	1150
Group 2	*Basisförderung Solar*	Gas- or oil-fired condensing boiler, heat pump or biomass-fired boiler with solar thermal support	Newly built 1- or 2-family home	1550
Group 3	*Basisförderung Wärmepumpe*	Heat pump	Existing or newly built 1- or 2-family home	1150
Group 4	*Basisförderung Biomasse*	Biomass-fired boiler	Existing or newly built home	1150

Organizational support for carrying out the pre- and the main study was kindly provided by BAFA. The mail package consisted of an accompanying letter by BAFA, stating the importance of the survey and encouraging the participation, the questionnaire with instructions, a stamped return envelope and a small give-away. After about one week, all participants received a postcard as a reminder. A replacement questionnaire was sent to all non-respondents after about five weeks. All these measures contributed to increase the overall response rate to 59.7% (*N*=2985). Similar surveys on the adoption of RHS in Germany and other European countries have achieved response rates between 15.1% and 48%.[15]

[14] For group 2, the pretest indicated a lower response rate. Therefore, we included more participants in group 2.

[15] Examples for Germany include Clausen (2008) on the adoption of solar thermal systems in Germany (15.1% - 23.8%) and Decker (2010) on the adoption of RHS (25.1%). Examples outside Germany include Mahapatra and

For the purpose of our analysis, we excluded all observations where the owner did not live in the home (i.e. no own usage of the home), where the home was a multi-family home, or where the main RHS was not a gas- or oil-fired condensing boiler, a heat pump or wood pellet-fired boiler. Therefore, the gross sample forming the basis of our analysis consisted of *N*=2682 observations (compared to initially 2985 observations). In a next step, drawing from the gross sample, we excluded all observations where at least one of the independent variables was missing (casewise deletion). Therefore, the net full sample consisted of 2240 complete observations, the net sample for the case of existing homes included 1214 observations, and the net sample for the case of newly built homes comprised 902 observations.

A large majority of homeowners installing a new RHS (partly) based on renewable energies applies for BAFA grants (cf. section 2.1). Therefore, drawing our sample from the BAFA database allows creating a representative sample of owners of 1- and 2-family homes that have purchased a new RHS. However, a potential bias arises from the fact that homeowners not applying for BAFA grants are not covered. Moreover, another possible drawback may stem from unequal external framework conditions for the grant recipients. In the period of time considered, homeowners faced changes in external framework conditions, such as a decrease in the size of the capital grants or fluctuations in energy prices or installation costs. This may have affected the homeowners' preferences and attitudes towards certain RHS over time. Another possible bias may stem from differences between the regional distributions of homes in our dataset compared to the total numbers of homes in Germany. Our dataset reflects pretty well the East-West divide while homes in the South of Germany are overrepresented.[16] However, our dataset gives a good representation of the regional distribution of the BAFA grant applicants.[17] There are also limitations with regard to the scales of measurement of certain variables (e.g. *Income* or *Size* are categorical variables).

4.2 Data description

Table 4 gives an overview of the variables used in our analysis.

Gustavsson (2008) on the adoption of RHS in Sweden (44% - 48%) or Sopha et al. (2011) on the adoption of wood pellet heating in Norway (19.4% - 44.6%).

[16] According to Destatis (2011a), about 15.4% of all 1- and 2-family homes were located in the East (our dataset: 12.3%) in 2009. About 29.8% of the 1- and 2-family homes were situated in the South (our dataset: 40.2%).

[17] Langniß et al. (2010) show that about 10.6% were from the East, while 62.6% originated from Bavaria and the Southwest (i.e. federal states Baden-Wuerttemberg, Hesse, Saarland, Rhineland-Palatinate) in 2009.

Table 4: Definition of variables

Variable	Definition
Dependent variable	
Residential heating system (RHS)	Installed RHS (GAS-ST = Gas-fired condensing boiler with solar thermal support, OIL-ST = Oil-fired condensing boiler with solar thermal support, HEAT-P = Heat pump, PELLET = Wood pellet-fired boiler with solar thermal support)
Independent variables	
Socio-demographic characteristics	
Income	Monthly net income of the household (1 < €2000, 2 = €2000 to €2999, 3 = €3000 to €3999, 4 = €4000 to €4999, 5 = €5000 to €5999, 6 > €6000)
Age	Age of the homeowner
University	Homeowner has a university degree (Yes = 1 / No = 0)
Female	Homeowner is a female (Yes = 1 / No = 0)
Home characteristics	
Size	Size of the home (1 < 100 m^2, 2 = 100 to 149 m^2, 3 = 150 to 199 m^2, 4 = 200 to 249 m^2, 5 > 250 m^2)
HomeAge	Age of the home
OneFam	Home is a 1-family home (Yes = 1 / No = 0)
Infrastructure	Home does not correspond to a standard home which limits the choice set (e.g. lack of suitable space for certain RHS, no storage room for wood pellets or oil, no basement or a lack of port) (Yes = 1 / No = 0)
EnConsult	Energy consultant and/or architect gave advice (Yes = 1 / No = 0)
PrevGas	Previous RHS gas-fired (Yes = 1 / No = 0)
PrevOil	Previous RHS oil-fired (Yes = 1 / No = 0)
PrevOther	Previous RHS other than gas- or oil-fired (Yes = 1 / No = 0)
Renovated	Home has been renovated since construction (Yes = 1 / No = 0)
Retrofit	Major retrofit and installation of the RHS at the same time (Yes = 1 / No = 0)
LowEn	Low energy home standard or better (Yes = 1 / No = 0)
Spatial characteristics	
Rural	Location in a rural region (Yes = 1 / No = 0)
East	Federal state belonging to Eastern Germany (Yes = 1 / No = 0)
South	Federal state Baden-Wuerttemberg or Bavaria (Yes = 1 / No = 0)
RHS-specific attributes	
Grant	Importance of the grant for the decision (5-point Likert scale)*
InvCost	Consideration of purchase costs (Yes = 1 / No = 0)
MainCost	Consideration of maintenance costs (Yes = 1 / No = 0)
EnergyCost	Consideration of current / perceived future energy costs (Yes = 1 / No = 0)
TotCost	Consideration of total costs over lifetime (Yes = 1 / No = 0)
EnSavings	Preference for energy savings (5-point Likert scale)*
Independent	Preference for more independence from fossil fuels (5-point Likert scale)*
Environment	Preference for environmental protection (5-point Likert scale)*
Comfort	Preference for ease of use (5-point Likert scale)*
Image	Preference for an improved image (5-point Likert scale)*

* The 5-point Likert scale ranges from “1” = “strongly disagree” to “5” = “strongly agree”.

The dependent variable represents the RHS chosen by each household; gas-fired condensing boiler with solar thermal support (GAS-ST), oil-fired condensing boiler with solar thermal support (OIL-ST), electric heat pump (HEAT-P) or wood pellet-fired boiler (PELLET). In our analysis, we consider the full sample (newly built and existing homes) as well as the two subsamples for existing and newly built homes in order to account for differences. Note that for the case of newly built homes, we excluded OIL-ST due the very limited number of cases.

Based on the literature review in the previous section, we use explanatory (independent) variables from four different categories to model the choice problem. First, socio-demographic characteristics of a homeowner (i.e. grant recipient) may influence the adoption decision. *Income* is a very important variable determining the financial possibilities of a household. *Age* of the homeowner reflects e.g. experience, risk aversion or desired payback period (i.e. older homeowners may require a shorter payback period than younger ones). We proxy the educational status with the variable *University*, i.e. the homeowner has a university degree. In line with Braun (2010), we argue that education can be a proxy for environmental awareness or an indicator for high opportunity costs of "home production". The latter argument can be motivated with the household production theory (Becker, 1965) that essentially states, among other, that the costs of "home production" increase with the higher opportunity costs of well-educated and/or high income households. Thus, homeowners with university education or high income are expected to decide about a RHS with a relatively low effort in terms of maintenance requirements or fuel acquisition, such as a heat pump or gas-fired condensing boiler with solar thermal support. With the variable *Female,* we control for gender effects.

Second, we assume that home characteristics will influence the adoption decision. The variable *Size* reflects the floor space and may capture effects from a higher heating demand. Age of the home (*HomeAge*) may serve as a proxy for the energy and technical standard of a building. The variable *OneFam* describes the type of home (i.e. a 1-family home or a 2-family home respective row house) and can be an indicator for size effects or particular energy demand patterns. The variable *Infrastructure* captures a deviation of the home from that of a typically standard home (e.g. no storage room for wood pellets or oil, no basement, lack of a gas port or of suitable installation space for certain RHS). Constraints imposed from such deviations may reduce the set of possible RHS choices. *EnConsult* reflects the involvement of professional advice (i.e. architect or energy consultant) in the decision making. The variables *PrevGas, PrevOil* and *PrevOther* capture effects stemming from the previous RHS installed in an existing building (e.g. habits and routines). The energy standard of the home (*Renovated, Retrofit, LowEn*) may serve as an indicator for a building's energy requirements.

Third, we consider spatial aspects. Spatial variables reflect framework conditions that cannot be attributed to the level of the individual owner and home.[18] The variable *Rural*[19] may reflect differences between urban and rural regions by capturing aspects such as the availability of storage space, larger homes or a better access to biomass in rural areas.[20] *East*[21] represents the area that formed until 1990 the former German Democratic Republic. The variable may account for a divide between East and West Germany by reflecting differences in the economic development or in energy and planning policies (e.g. promotion of district heating) before the reunification. The variable *South*[22] accounts for a possible North-South divide by reflecting e.g. the higher solar irradiation or a less developed gas grid in the south of Germany.[23]

Lastly, we consider RHS-specific attributes. These include the consideration of cost aspects and preferences related to RHS. The variable *Grant* reflects the importance of the BAFA grant for the adoption decision. Moreover, we include variables to account for the consideration of different cost types, such as purchase (*InvCost*), maintenance (*MainCost*), energy (*EnCost*) and total costs (*TotCost*) in the decision-making process. We take into account five variables capturing preferences related to the RHS adoption decision. *EnSav* captures the preference for saving energy, *Independent* the preference for being more independent from fossil fuels, *Enviro* the intention to protect the environment, *Comfort* a preference for an improved ease of use related to the RHS (e.g. fuel acquisition or maintenance requirements) and *Image* the preference for an improved image among significant others. Table 5 shows the summary statistics for each sample.

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[18] We also checked for possible correlations between the spatial variables and *Infrastructure*. We only find a small positive correlation between *East* and *Infrastructure* (0.072***). Correlations between the pairs *Infrastructure* and *Rural* respective *South* were not found to be statistically significant.

[19] We label districts as rural if they have a population density of less than 150 inhabitants per km^2. For this purpose, we use the categorization of districts (*zusammengefasste Kreistypen 2008*) according to BBSR (2011a). About 66.8% of the population in Germany lives in urban regions (BBSR, 2011c).

[20] According to BBSR (2011b), the living space per tenant is higher in rural (West: 46.5 m^2, East: 40.2 m^2) than in urban regions (West: 41.1–44.6 m^2, East: 38.8–39.7 m^2). Langniß et al. (2010) state that biomass- based RHS can be found in regions with a relatively high share of forest area (i.e. South and Southwest).

[21] The federal state of Berlin is matched to West Germany.

[22] “South” includes the federal states of Bavaria and Baden-Wuerttemberg.

[23] According to EnergieMarktDaten (2011), the gas grid is less developed in the South and East of Germany (i.e. fewer communities belong to a region respective market area where gas is supplied). A possible reason for this may be that the South is more rural or mountainous which makes the development of a gas network difficult.

Table 5: Summary statistics for the full sample, sample of existing homes and sample of newly built homes

Variable	**Full sample**		**Existing homes**		**Newly built homes**	
Dependent variable **Residential heating system**	**N**	**%**	**N**	**%**	**N**	**%**
GAS-ST	629	28.1	318	26.2	271	30.0
OIL-ST	236	10.5	204	16.8	0	0.0
HEATPUMP	818	36.5	243	20.0	542	60.1
WOODPELLET	557	24.9	449	37.0	89	9.9
Explanatory variables **Socio-demographic characteristics**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Income (6 categories)	2.881	1.340	2.752	1.355	3.132	1.293
Age (metric)	48.271	12.603	53.269	11.557	40.834	9.872
University (1 if Yes)	0.352	0.478	0.301	0.459	0.445	0.497
Female (1 if Yes)	0.158	0.365	0.128	0.334	0.191	0.393
Home characteristics						
Size (5 categories)	2.794	0.989	2.904	1.032	2.676	0.921
HomeAge (metric)	28.612	36.163	48.056	36.001		
OneFam (1 if Yes)	0.754	0.431	0.639	0.480	0.920	0.271
Infrastructure (1 if Yes)	0.250	0.433	0.249	0.432	0.253	0.435
EnConsult (1 if Yes)	0.394	0.489	0.336	0.473	0.494	0.500
PrevGas (1 if Yes)			0.295	0.456		
PrevOil (1 if Yes)			0.585	0.493		
Renovated (1 if Yes)			0.611	0.488		
Retrofit (1 if Yes)			0.306	0.461		
LowEn (1 if Yes)					0.621	0.485
Spatial characteristics						
Rural (1 if Yes)	0.355	0.479	0.377	0.485	0.326	0.469
East (1 if Yes)	0.123	0.328	0.098	0.297	0.165	0.372
South (1 if Yes)	0.402	0.490	0.439	0.496	0.354	0.478
RHS-specific attributes						
Grant (5-point Likert scale)*	2.445	1.010	2.627	1.005	2.191	0.966
InvCost (1 if Yes)	0.838	0.369	0.865	0.342	0.809	0.393
MainCost (1 if Yes)	0.476	0.500	0.539	0.499	0.394	0.489
EnCost (1 if Yes)	0.790	0.408	0.848	0.359	0.721	0.449
TotCost (1 if Yes)	0.740	0.439	0.777	0.417	0.700	0.459
EnSavings (5-point Likert scale)*	4.366	0.856	4.364	0.864	4.367	0.831
Independent (5-point Likert scale)*	3.826	1.127	3.808	1.114	3.881	1.142
Environment (5-point Likert scale)*	4.138	0.965	4.238	0.900	3.989	1.039
Comfort (5-point Likert scale)*	3.193	1.131	3.079	1.127	3.319	1.122
Image (5-point Likert scale)*	1.936	1.089	1.962	1.101	1.878	1.066
Number of observations	2240		1214		902	
thereof newly built homes	917		0		902	
thereof existing homes	1323		1214		0	

* The 5-point Likert scale ranges from "1" = "strongly disagree" to "5" = "strongly agree".

5 Model specification

For our empirical analysis, we designed a discrete choice model for investigating the probability that a homeowner chooses a specific RHS out of a choice set of more than two alternatives. Since our dependent variable represents an unordered choice that can be any one of four types of RHS, we use a multinomial logit model (MNL).

The decision to adopt a certain RHS is modeled within a random utility modeling framework. A homeowner i (i = 1, 2, …, I) makes a selection out of a finite set of alternatives J (j = 1, 2, …, J). Thus, the utility of a certain alternative j is:

$$U_{i,j} = \beta_j x_i + \varepsilon_{i,j} \tag{1}$$

$U_{i,j}$ represents the utility of homeowner i of RHS j, x_i represent explanatory variables (e.g. age, size of the home, South), β_j unknown coefficients and $\varepsilon_{i,j}$ the error term. We observe homeowner i to adopt RHS j, when the utility from RHS j is the highest compared to all other RHS in the choice set.

A MNL framework is applied, as the explanatory variables represent characteristics of the homeowners, and errors are assumed as independently and identically distributed according to the type I extreme value distribution (Gumbel distribution).The MNL model specifies the following choice probability of a homeowner i for RHS of type j (j=1, 2, …, J):

$$Prob(RHS_j) = P_{i,j} = \frac{\exp(\beta_j x_i)}{1 + \sum_{k=1}^{J} \exp(\beta_k x_i)} \text{ for } j = 1, 2, \ldots, J. \tag{2}$$

In order to interpret the results from the MNL analysis, marginal effects of a change in variable x_i have to be calculated. This has to be done since a coefficient's magnitude and sign in non-linear models cannot be interpreted directly as the marginal effect of variable x_i on the dependent variable (choice probability) P_{ij}. The marginal effect of a change in variable x_i is:

$$\frac{\partial P_{i,j}}{\partial x_i} = P_{i,j}\left[\beta_j - \sum_{k=0}^{J} P_{ik}\beta_k\right] \tag{3}$$

Equation (3) shows that the marginal effect does not depend on the coefficient's estimate β_j alone, but also on the remaining coefficient estimates and variables.

The independence from irrelevant alternatives (IIA) is an important assumption of the MNL approach, i.e. the relation of the probabilities for choosing any two alternatives is independent of the presence of any other alternative. In order to examine the validity of this assumption, a Hausman test can be applied (Hausman and McFadden, 1984).

6 Results and discussion

In a first step, we present the results for the full sample.[24] Secondly, we consider the two sub-samples of owners of existing homes and owners of newly built homes. This allows exploring some differences in the relevance of certain variables across different groups of owners.

For all samples, we performed Hausman and Likelihood Ratio (LR) tests to examine the robustness and quality of our empirical approach.[25] The results of the Hausman tests show that the IIA assumption holds for each sample. Thus, the MNL regression approach is a suitable empirical approach for the purpose of our study. Moreover, LR tests for the dependent variables show that merging categories does not improve the quality of the results.

6.1 Results for the full sample

In the following, we present and discuss the findings for the full sample in some more detail.

- *Socio-demographic characteristics:* The results presented in table 6 show that socio-demographic variables are important determinants of the homeowners' decisions. In particular, *Income*, *Age* and *University* seem to be relevant variables. For all types of RHS, *Income* is significant. *Income* has a positive impact on the probability to choose either *GAS-ST* (0.017^{***}) or *HEAT-P* (0.013^{*}), for an otherwise equivalent household. For *OIL-ST* and *PELLET*, we observe a negative relationship. The probability to choose either *OIL-ST* (-0.016^{***}) or *PELLET* (-0.014^{**}) decreases with a higher income level. However, all income-related effects are minor. These findings correspond to the findings from other studies. For instance, Braun (2010) finds for the case of Germany that richer households avoid oil- and solid fuel-based RHS, while they favor to use gas-fired RHS.[26] Vaage (2000) finds for Norway that wealthier households tend to choose electricity as the only RHS, while combinations of electricity with solid fuels (biomass) or oil are rather unpopular. The variable *Age* is barely significant for all RHS except *GAS-ST*. *Age* has a positive impact on *OIL-ST* (0.004^{***}), while it has a negative influence on *HEAT-P* (-0.003^{***}) and *PELLET* (-0.001^{**}). This implies that

[24] We present our results as average marginal effects (M.E.). Marginal effects display how a change by one unit in one of the independent variables affects the predicted probability of belonging to one category, leaving the other explanatory variables constant. *** (1%), ** (5%) or * (10%) indicate the level of significance.

[25] The test statistics of the Hausman and LR tests can be found in tables A1 and A2 in the appendix.

[26] In Braun (2010), solid fuel-based RHS include biomass, briquette and coal as fuel, while *PELLET* in our research is only biomass-based. Moreover, the research of Braun (2010) or Vaage (2000) is based on data much older than our data. This should be kept in mind when interpreting our findings in the context of similar research.

older homeowners favor an oil-fired solution, while younger homeowners are more open towards innovative RHS, such as a heat pump or wood pellet-fired boiler. *Age* may also reflect differences in the risk aversion. The level of education (*University*) has a positive impact on *GAS-ST* (0.030*) and *HEAT-P* (0.046**), while it has a negative influence on *PELLET* (-0.063***). These findings also correspond to Braun (2010), who shows that households with higher education tend to apply gas-fired solutions, while households with a lower education tend to have solid fuel-fired systems installed. The findings for *Income* and *University* can also be motivated with Becker's household production theory (cf. section 4.2). The variable *Female* is only significant for *GAS-ST* (0.043**). For example, females may have a higher risk aversion and therefore prefer an established and proven RHS such as a gas-fired system.

- *Home characteristics:* The variables *Size*, *HomeAge* and *Infrastructure* seem to be important determinants for the homeowners' decisions. *HomeAge* has a small positive impact on *OIL-ST* (0.001***) and *PELLET* (0.002***) whereas the influence on *HEAT-P* is negative (-0.004***). This corresponds to the findings of Braun (2010) who shows that gas-fired RHS are more likely to be found in younger homes while the probability for a solid fuel-based or oil-fired RHS applied increases with the age of the building. *Size* has a positive influence on *OIL-ST* (0.017***) and *HEAT-P* (0.033***), whereas it has a negative impact on *GAS-ST* (-0.053***). Possible reasons for that can be that larger homes have enough space for an oil tank or are more suitable for floor heating. In case there are any constraints imposed by the infrastructure of the home (*Infrastructure*), we can observe a positive influence on the probability to adopt *GAS-ST* (0.05***) and *OIL-ST* (0.03**) and a negative influence on *PELLET* (-0.05**). This shows that homeowners select established and proven RHS in case their home does not correspond to that of a standard home. The variable *EnConsult* (i.e. professional advice from energy consultants or architects) has a negative impact on *OIL-ST* (-0.037***) only. A possible reason for dissuasion by architects and energy consultants can be, for example, the sharp increase of the oil prices in the recent past and the likely continuation of this trend in the future. Moreover, they may also see oil-based RHS as an obsolete technology with relatively high space requirements and a low ease of use compared to alternative RHS.

- *Spatial characteristics:* Overall, spatial characteristics are found to be highly significant in most cases. In particular, *East* and *South* are significant for all RHS. *East* has a negative impact on *GAS-ST* (-0.049**), *OIL-ST* (-0.075***) and *PELLET* (-0.082***), while a location in East Germany strongly increases the probability for *HEAT-P* (0.206***). This may reflect differences in the price and distribution system of wood pellets, a long history in space heating based on district heating or in the usage of the fuels lignite and coal rather than oil, better insulated homes or a lower density of the gas grid in certain regions (c.f. section 4.2). A location in the *South* has a negative impact on the probability to choose *GAS-ST* (-0.088***) and *HEAT-P* (-0.03*), whereas the probability for *OIL-ST* (0.039***) and *PELLET* (0.079***) increases. For example, this can reflect that the gas grid is less developed in the South and that there is a longer history of heating with oil- or biomass-based RHS. *Rural* increases the probability to choose *OIL-ST* (0.026**) and lowers the probability to adopt *HEAT-P* (-0.041**). Possible explanations are that the gas grid is generally less developed in rural areas and that a heat pump is more likely to be installed in urban regions where space is scarcer.

- *RHS-specific attributes:* With regard to economic aspects in the decision-making process, we find that *Grant* has a positive impact on *PELLET* (0.056***) and a negative influence on *HEAT-P* (-0.042***). This implies that the amount of the grant may be valued differently. Moreover, wood pellet-fired boilers have the highest purchase costs among all RHS (cf. table 2). We find a negative impact of *MainCost* on the RHS *OIL-ST* (-0.021*), while there is a positive influence on *HEAT-P* (0.048***). *EnCost* has a strong negative impact on the adoption of *HEAT-P* (-0.1***), whereas there is strong positive influence on *PELLET* (0.111***). *TotCost* is not considered for *GAS-ST* (-0.097***), whereas it has a positive influence on *HEAT-P* (0.069***). Overall, we find that homeowners do not seem to reflect on all types of costs when taking their decisions. They rather include or exclude certain costs in the decision-making process. Possible reasons for this evidence can be that homeowners are not fully aware of all costs at the purchase stage or that some costs, such as for maintenance, are relatively small.

The variables *EnSavings*, *Independent* and *Comfort* are found to be important in the homeowners' decision-making processes. Overall, their impact and direction varies across groups of RHS adopters. *Comfort* is highly significant for all RHS. We find a positive impact on the probability to adopt the heating systems *GAS-ST* (0.038***) and *HEAT-P* (0.051***), whereas there is a negative influence on *OIL-ST* (-0.016***) and *PELLET* (-0.073***). The results show that homeowners with a preference for comfort favor technologies with a relatively high ease of use, such as a gas-fired system or a heat pump. *Independent* is also highly statistically significant for all RHS. There is a negative influence on adopting *GAS-ST* (-0.150***) and *OIL-ST* (-0.043***), however we can observe a highly positive impact on *HEAT-P* (0.1***) and *PELLET* (0.093***). These results correspond to the properties of the respective fuels. *GAS-ST* and *OIL-ST* are fired with fossil fuels, while the other two RHS do not (directly) rely on fossil fuels. *EnSavings* has a positive bearing on *GAS-ST* (0.054***) and *OIL-ST* (0.057***), whereas the influence on *PELLET* is negative (-0.109***). This shows that homeowners purchasing a gas- or oil-fired condensing boiler prefer an energy-efficient RHS. *Environment* has a positive impact on *PELLET* (0.024***), while the influence on *HEAT-P* is negative (-0.022**). This shows that environmental protection is indeed important for homeowners adopting *PELLET*. Finally, we find that the variable *Image* is not significant for any RHS.

Table 6: Results for the full sample (*N*=2240)

	GAS-ST		**OIL-ST**		**HEAT-P**		**PELLET**	
	M.E.	S.E.	M.E.	S.E.	M.E.	S.E.	M.E.	S.E.
Income	**0.017*****	0.007	**-0.016*****	0.005	**0.013***	0.007	**-0.014****	0.006
Age	0.000	0.001	**0.004*****	0.000	**-0.003*****	0.001	**-0.001****	0.001
University	**0.030***	0.018	-0.014	0.014	**0.046****	0.019	**-0.063*****	0.016
Female	**0.043****	0.021	-0.017	0.016	-0.029	0.022	0.003	0.019
Size	**-0.053*****	0.009	**0.017*****	0.006	**0.033*****	0.009	0.003	0.007
HomeAge	**0.000***	0.000	**0.001*****	0.000	**-0.004*****	0.000	**0.002*****	0.000
OneFam	0.009	0.020	-0.013	0.014	**0.037***	0.022	**-0.032***	0.017
Infrastructure	**0.050*****	0.018	**0.030****	0.014	-0.030	0.020	**-0.050****	0.017
EnConsult	0.012	0.016	**-0.037*****	0.012	0.022	0.017	0.003	0.014
Rural	-0.021	0.017	**0.026****	0.013	**-0.040****	0.018	0.036	0.015
East	**-0.049****	0.023	**-0.075*****	0.015	**0.206*****	0.030	**-0.082*****	0.024
South	**-0.088*****	0.017	**0.039*****	0.012	**-0.030***	0.018	**0.079*****	0.015
Grant	-0.009	0.008	-0.005	0.006	**-0.042*****	0.008	**0.056*****	0.007
InvCost	0.018	0.021	0.012	0.015	0.000	0.024	-0.030	0.021
MainCost	-0.012	0.017	**-0.021***	0.013	**0.048*****	0.018	-0.015	0.015
EnCost	-0.018	0.020	0.007	0.015	**-0.100*****	0.025	**0.110*****	0.020
TotCost	**-0.097*****	0.021	0.012	0.015	**0.069*****	0.023	0.017	0.019
EnSavings	**0.054*****	0.011	**0.057*****	0.009	-0.002	0.010	**-0.109*****	0.007
Independent	**-0.150*****	0.005	**-0.043*****	0.004	**0.100*****	0.008	**0.093*****	0.008
Environment	0.002	0.009	-0.003	0.006	**-0.022****	0.009	**0.024*****	0.008
Comfort	**0.038*****	0.007	**-0.016*****	0.005	**0.051*****	0.007	**-0.073*****	0.006
Image	-0.008	0.007	0.001	0.005	0.005	0.008	0.002	0.006
Log-likelihood	-1792.75							
Pseudo-R^2	0.39							
N	2240							

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

6.2 Results for existing homes

We include *PrevGas* and *PrevOil* to capture the impact of the previously installed RHS.[27] Moreover, *Renovated* and *Retrofit* are supposed to account for effects stemming from an improved energy standard of the home or a parallel retrofit and installation of a new RHS. Table 7 presents the results for this subsample.

[27] Recall that the reference category is “any other previously installed RHS not based on the fossil fuels oil or gas” (e.g. electric heating, biomass- or coal-fired RHS).

Table 7: Results for existing homes (*N*=1214)

	GAS-ST			OIL-ST			HEAT-P			PELLET		
	M.E.		S.E.	M.E.		S.E.	M.E.		S.E.	M.E.		S.E.
Income	0.002		0.007	**-0.012**	*	0.007	**0.025**	***	0.008	**-0.014**	*	0.008
Age	**0.002**	***	0.001	**0.003**	***	0.001	-0.001		0.001	**-0.004**	***	0.001
University	0.013		0.019	0.033		0.021	0.004		0.024	**-0.051**	**	0.024
Female	**0.074**	***	0.026	**-0.050**	**	0.023	-0.030		0.029	0.007		0.029
Size	**-0.019**	**	0.009	0.009		0.008	**0.022**	**	0.011	-0.013		0.010
HomeAge	0.000		0.000	0.000		0.000	**-0.001**	***	0.000	**0.001**	***	0.000
OneFam	0.009		0.018	0.018		0.017	-0.003		0.022	-0.024		0.022
Infrastructure	**0.056**	***	0.019	**0.044**	**	0.020	**-0.051**	**	0.024	**-0.049**	**	0.025
EnConsult	0.005		0.018	-0.022		0.017	0.006		0.022	0.012		0.021
PrevGas	**0.535**	***	0.070	**-0.112**	*	0.062	**-0.155**	***	0.032	**-0.268**	***	0.033
PrevOil	0.003		0.041	**0.208**	***	0.038	**-0.142**	***	0.031	**-0.069**	***	0.030
Renovated	0.009		0.018	-0.018		0.017	0.005		0.023	0.004		0.023
Retrofit	0.010		0.020	-0.011		0.020	0.015		0.025	-0.014		0.024
Rural	0.005		0.017	-0.008		0.016	-0.012		0.021	0.015		0.021
East	**-0.060**	**	0.027	**-0.071**	**	0.030	**0.207**	***	0.046	**-0.075**	*	0.039
South	**-0.049**	***	0.017	**0.034**	**	0.016	-0.030		0.023	**0.045**	**	0.022
Grant	0.004		0.009	**-0.017**	**	0.008	**-0.038**	***	0.011	**0.050**	***	0.010
InvCost	0.008		0.024	0.016		0.022	-0.007		0.033	-0.017		0.033
MainCost	-0.024		0.018	**-0.035**	**	0.018	**0.088**	***	0.022	-0.028		0.022
EnCost	-0.010		0.025	-0.015		0.026	**-0.136**	***	0.040	**0.161**	***	0.035
TotCost	-0.023		0.022	0.001		0.022	0.028		0.030	-0.007		0.030
EnSavings	**0.047**	***	0.012	**0.095**	***	0.012	-0.012		0.013	**-0.130**	***	0.011
Independent	**-0.079**	***	0.007	**-0.081**	***	0.007	**0.038**	***	0.011	**0.122**	***	0.011
Environment	-0.005		0.009	-0.007		0.009	-0.018		0.012	**0.029**	**	0.012
Comfort	**0.029**	***	0.007	0.000		0.007	**0.061**	***	0.009	**-0.089**	***	0.009
Image	-0.009		0.008	0.009		0.008	-0.006		0.009	0.006		0.009
Log-likelihood	-800.98											
Pseudo-R^2	0.51											
N	1214											

Notes: Average Marginal Effects (M.E.), Superscripts ***, ** and * indicate statistical significance at 1%, 5% and 10% level, respectively. Reference category: GAS-ST.

Overall, the results correspond with the findings from the full sample. Therefore, we focus on the additionally included variables. We find a strong positive influence of *PrevGas* on *GAS-ST* (0.535***), while there is a negative impact on *OIL-ST* (-0.112*), *HEAT-P* (-0.155***) and *PELLET* (-0.268***). *PrevOil* has a strong positive impact on *OIL-ST* (0.208***), however the influence on *HEAT-P* (-0.142***) and *PELLET* (-0.069***) is negative. This implies that adopters of *HEAT-P* and *PELLET* are more likely to replace another, non-oil- or gas-fired (e.g. electric or coal-fired) RHS. Moreover, homeowners seem to stick to a RHS they are familiar with. They may fear to change their RHS-related habits. Thus, prevailing habits and routines seem to be key determinants for the adoption decision. This is also a possible explanation for a certain persistency in the current stock of RHS and the slow take-up of innovative RHS in existing homes (cf. section 2.2). Moreover, it is often much easier to replace the existing RHS by the same system. A switch from e.g. a gas-fired RHS to *OIL-ST* or *PELLET* requires allocating space for a storage room. Finally, we find no statistically significant results for *Renovated* and *Retrofit*.

6.3 Results for newly built homes

In this analysis, we exclude *OIL-ST* due to the low number of observations. We also exclude *HomeAge* since all homes were built in the same years (2008-2010). In turn, we introduce *LowEn* to account for a low energy home. Table 8 presents the results for newly built homes.

Table 8: Results for newly built homes (*N*=902)

	GAS-ST			HEAT-P			PELLET		
	M.E.		S.E.	M.E.		S.E.	M.E.		S.E.
Income	0.009		0.010	0.006		0.011	**-0.015**	**	0.007
Age	0.000		0.001	0.000		0.001	0.000		0.001
University	-0.007		0.024	0.037		0.028	**-0.030**	*	0.018
Female	-0.006		0.026	-0.041		0.033	**0.047**	*	0.024
Size	**-0.056**	***	0.013	**0.032**	**	0.016	**0.024**	**	0.010
OneFam	-0.032		0.042	0.070		0.050	-0.038		0.035
Infrastructure	**0.051**	*	0.026	-0.029		0.031	-0.022		0.020
EnConsult	0.007		0.022	-0.009		0.026	0.002		0.017
LowEn	**-0.131**	***	0.025	**0.100**	***	0.029	**0.030**	*	0.018
Rural	0.023		0.025	**-0.061**	**	0.029	**0.038**	**	0.019
East	**-0.134**	***	0.028	**0.118**	***	0.043	0.016		0.036
South	**-0.050**	**	0.024	**-0.058**	*	0.031	**0.108**	***	0.023
Grant	-0.007		0.012	**-0.033**	**	0.014	**0.040**	***	0.008
InvCost	0.027		0.029	-0.002		0.036	-0.025		0.025
MainCost	0.031		0.025	0.004		0.029	**-0.036**	**	0.018
EnCost	-0.008		0.026	-0.045		0.031	**0.054**	***	0.020
TotCost	**-0.105**	***	0.031	**0.116**	***	0.036	-0.011		0.022
EnSavings	**0.037**	**	0.015	0.011		0.017	**-0.048**	***	0.010
Independent	**-0.173**	***	0.007	**0.148**	***	0.012	**0.026**	**	0.010
Environment	**0.019**	*	0.011	**-0.026**	*	0.013	0.007		0.009
Comfort	**0.022**	**	0.010	**0.024**	**	0.012	**-0.046**	***	0.008
Image	**-0.022**	**	0.011	0.011		0.012	0.011		0.008
Log-likelihood	-468.76								
Pseudo-R^2	0.42								
N	902								

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

Again, the findings reflect the overall tendency of the results from the full sample. *LowEn* has a significant impact on all RHS. We find a positive impact on *HEAT-P* (0.1^{***}) and on *PELLET* (0.03^{*}). For example, this reflects that the low flow temperature of heat pumps makes this system more suitable for homes with low energy requirements. *GAS-ST* is more likely installed in homes constructed only according to the minimum requirements for the energy standard (-0.13^{***}).[28]

6.4 Comparison of the findings for existing and newly built homes

For all pairs of significant variables with the same name, we compare the findings for existing and newly built homes according to the RHS *GAS-ST*, *HEAT-P* and *PELLET*, respectively.[29] This allows us to show the impact of different factors on the choice of a certain RHS in either an existing or a newly built home. Moreover, we discuss possible reasons for differences in the variables between the two subsamples.

6.4.1 Gas-fired condensing boiler with solar thermal support (*GAS-ST*)

The presence of constraints stemming from the infrastructure of the home (*Infrastructure*) positively influences the probability to choose *GAS-ST* in both existing (0.056^{***}) and newly built (0.051^{*}) homes. A gas-fired system is easy to integrate in any home with access to the gas network or a chimney available. For example, there is no need for a basement accommodating the fuel storage room. *Size* has a negative effect on the adoption of *GAS-ST*, for both existing (-0.019^{**}) and newly built homes (-0.056^{***}). Since this RHS has relatively low space requirements and can easily be integrated into a home's bathroom, kitchen or utility room, it is in particular suitable for smaller homes.

Spatial aspects have a strong negative impact on the probability to adopt *GAS-ST*. *East* decreases the probability to choose *GAS-ST* for both existing (-0.06^{**}) and newly built homes (-0.134^{***}). The same applies for the South of Germany (*South*) for existing (-0.049^{***}) and newly built homes (-0.05^{**}). In particular in the East, new development areas seem to be less likely to be connected to the gas network. For example, this can be due to the lower energy density (i.e. energy requirements) in new development areas, which makes it from economic point of view less attractive for the grid operator to invest into an extension of the gas grid.

[28] For example, homeowners did not choose the latest insulation standard in such cases. They rather selected a no more than absolutely necessary insulation level in order to fulfill the minimum requirements imposed by law.

[29] Since *OIL-ST* was excluded from newly built homes, this RHS is not further analyzed here.

Homeowners choosing *GAS-ST* have a clear preference for energy savings (*EnSavings*). There is a higher preference for energy savings in existing homes (0.047^{***}) than in newly built homes (0.037^{**}). Reasons for this difference can be that owners of existing homes previously had RHS that were outdated and had relatively high energy consumption and costs. Both, owners of existing (0.029^{***}) and newly built (0.022^{**}) homes have a preference for comfort (*Comfort*), i.e. they prefer a system with a high ease of use. When choosing *GAS-ST*, there is no preference towards being more independent (*Independent*) of fossil fuels. For newly built homes, this effect is much higher (-0.173^{***}) than for existing homes (-0.079^{***}). Thus, adopters of *GAS-ST* seem to care less about energy security issues.

6.4.2 Heat pump (*HEAT-P*)

The floor size of the home (*Size*) positively influences the choice probability for *HEAT-P* in both existing (0.022^{**}) and newly built homes (0.032^{**}). Thus, this RHS seems to be more suited for larger homes (e.g. the relative cost savings compared to other RHS increase with the floor size). Furthermore, we find spatial aspects to be relevant. *East* has a positive impact on both existing (0.207^{***}) and newly built homes (0.119^{***}). Reasons for the relatively high impact on the choice probability for the case of existing homes can be specific framework conditions that disfavor other RHS, such as no gas grid, a lack of history in heating with oil as fuel, or relatively high prices for wood pellets in this region.

Moreover, the BAFA grant (*Grant*) is less important for adopting *HEAT-P* in both the case of existing (-0.038^{***}) as well as newly built homes (-0.033^{**}). Preferences for the independence of fossil fuels for heating purposes (*Independent*) increase the probability to choose *HEAT-P*. The choice probability is lower for the case of existing (0.038^{***}) than newly built homes (0.148^{***}). A preference for an improved comfort related to the RHS (*Comfort*) has a higher impact on the choice probability in existing (0.061^{***}) than in newly built homes (0.024^{**}). This shows that owners of existing homes rather care about an improved comfort while the independence from oil and gas seems to be more relevant in the case of newly built homes.

6.4.3 Wood pellet-fired boiler (*PELLET*)

In general, socio-demographic characteristics are found to be relevant for the adoption of *PELLET* in both existing and newly built homes. Homeowners adopting *PELLET* seem to be different from adopters of other RHS. We find that a higher income (*Income*) has a negative impact on the choice probability in both existing (-0.014^{*}) and newly built homes (-0.015^{**}). We also find education (*University*) to have a negative influence for the case of existing

(-0.051**) and newly built homes (-0.03*). Homeowners with a university education tend to adopt a RHS other than *PELLET*. The findings on income and education reflect Becker's household production theory (cf. section 4.2). This implies that the costs of home production related to *PELLET* (e.g. fuel acquisition, cleaning or maintenance work) increase with the higher opportunity costs of households with higher education or income.

Further, we find that spatial aspects do have an impact on the adoption of *PELLET*. A location in the South (*South*) increases the choice probability for existing (0.045**) and newly built homes (0.108***). In particular, the effect on newly built homes is relatively high. For example, this can reflect a tradition of heating with biomass, a better access to biomass in this region or a less developed gas network.

For both, owners of existing (0.05***) and newly built homes (0.04***), the capital grant by BAFA (*Grant*) is important for the adoption of *PELLET*. This may reflect the relatively higher purchase costs. Energy costs (*EnCosts*) are considered in both existing (0.161***) and newly built homes (0.054***). In particular for existing homes, the reflection of energy costs increases the probability to choose *Pellet*. A possible reason can be that the development of the price of wood pellets differs significantly from that of other fuels for residential space heating. For example, owners of existing homes replacing their old RHS with *PELLET* may have experienced the past increase in the fuel prices for oil and gas as particularly strong.

Owners of existing homes adopting *PELLET* have a clear preference (0.122***) for being independent of fossil fuels for heating (*Independent*). In contrast, this effect is relatively smaller for owners of newly built (0.026**). An increased preference for energy savings (*EnSavings*) has a negative impact on both existing (-0.13***) and newly built homes (-0.048***). Moreover, we can observe a negative influence of a preference *Comfort* on the choice probability for both existing (-0.089***) and newly built homes (-0.046***). This shows that preferences about energy savings and comfort considerations are irrelevant for the decision. Homeowners rather consider independence of fossil fuels as an important for their decision. Similar to *EnCosts*, this may reflect the past experience with the fuels applied for residential heating.

7 Conclusions

Space heating accounts for a large fraction of the primary energy consumption and CO_2 emissions of residential buildings in Germany. Besides targeting the insulation of homes, renewables-based RHS offer the potential to reduce residential energy demand and CO_2 emissions. Therefore, understanding the determinants of the homeowners' RHS adoption decision becomes increasingly important. The aim of this research was to empirically analyze the adoption decision at the micro-level by accounting for the heterogeneity of adopters and behavioral aspects. So far, studies on energy appliance choice have mostly focused on the influence of socio-demographic, home and spatial characteristics, while preferences about RHS-specific attributes have been considered much less by the previous literature. Moreover, these studies mostly rely on ownership data. Thus, our research makes a contribution to a better understanding of the specific preferences in the decision-making process by using both stated and revealed preferences data on the actual (rather than hypothetical) adoption decision. However, a limitation of this study is that the focus is on RHS adoption only. The RHS adoption decision is often embedded into a bundle of decisions related to other attributes of the home. In particular, for the case of newly built homes, the decision is often just one decision among a number of others. Owners of newly built homes have to decide about the insulation standard, construction of a basement or floor heating. These decisions have implications for the choice of the heating system. Therefore, it would be interesting to explore the dynamics of the decision-making process if owners have to decide between different packages of components (cf. Kumbaroğlu and Madlener, 2011). Another limitation is the focus on homeowners who have taken a decision about a RHS very recently.

In this research, we show that there are different drivers behind the RHS adoption decision. Besides socio-demographic, home and spatial characteristics, preferences about RHS-specific attributes are found to be significant determinants of the homeowners' adoption decisions. The importance of key drivers also differs across RHS and groups of homeowners, respectively. This implies that the RHS adoption decision is a rather complex process. Spatial aspects are found to be relevant for both newly built and existing homes. They set the basis for the adoption decision by reflecting more general framework conditions on the regional level, i.e. conditions that cannot be assigned to an individual home or homeowner. Overall, the choice of a RHS in newly built homes seems to be highly influenced by preferences about certain characteristics of the home, such as size or energy standard. This implies that homeowners make a decision about a bundle of attributes related to the home (including the energy standard and size of the home as well as RHS-specific attributes) rather than making an isolated decision about the RHS *per se*. In many cases, construction companies offer newly built homes as packages where the RHS as a component cannot (easily) be changed. In contrast, owners of existing homes seem to focus their decision mainly on the RHS itself. Thus, the choice seems to be much more influenced by given individual framework conditions on the level of the building or owner. This means that variables that can only be hardly altered, such as infrastructural constraints, age of the home, and the homeowner's age or income, do have an impact on the adoption decision. Moreover, the decision is strongly shaped by habits and previous experiences with certain RHS. These variables constrain the impact of preferences about RHS-specific attributes on the adoption decision. In contrast to newly built homes, preferences seem to play a less important role in existing homes. For the heat pump and the wood pellet-fired boiler, we find that homeowners evaluate different cost aspects more carefully than in the case of other RHS. Finally, we find that the grant is important for the choice of a wood pellet-fired boiler in both existing and newly built homes, i.e. the availability and amount of the grant has a direct impact on the adoption decision. For the heat pump and the oil-fired condensing boiler with solar thermal support, we find the grant to be less relevant for the adoption decision. Likewise, we find no evidence on the importance of the grant for the gas-fired condensing boiler with solar thermal support.

The finding that the BAFA grant does not play a role in the decision-making process for certain RHS has economic implications. In such cases, the grant is not economically efficient since the homeowners would have bought the RHS anyway. Therefore, this instrument should focus on RHS where there was a positive influence on the adoption decision (i.e. *PELLET*). Furthermore, the emphasis of the capital grant could be more on innovative RHS that are above the technical standard regarding e.g. their fuel efficiency or CO_2 emissions (compared to other RHS of the same type). These criteria should be reviewed and revised on a frequent basis. This would help the most innovative RHS to gain market shares and increase the economic efficiency and environmental effectiveness of the BAFA grant.

Moreover, we can draw some managerial implications from our research. RHS manufacturers can improve their marketing strategies by putting a stronger focus on the significant determinants of the adoption decision. For example, heat pump manufacturers should emphasize aspects related to the independence from fossil fuels, such as gas and oil or the comfort of the RHS.

Finally, our research has also policy implications. Energy and climate policy measures targeting RHS should consider the heterogeneity of homeowners by taking into account behavioral aspects as well as framework conditions on the individual, home and regional level. For example, policy instruments aiming at biomass-fired RHS may have more success in the South of Germany. Moreover, policy measures targeting RHS can be tailored according to different types of homes (e.g. age of the home, energy standard or size).

Appendix

Table A1: Hausman tests of IIA assumption

Sample / Reduced model	OIL-ST			HEAT-P			PELLET		
Full sample	χ^2	df	$p > \chi^2$	χ^2	df	$p > \chi^2$	χ^2	df	$p > \chi^2$
Model *b1* (OIL-ST omitted)	omitted			25.95	23	0.30	24.37	23	0.38
Model *b2* (HEAT-P omitted)	29.01	23	0.18	omitted			31.60	23	0.11
Model *b3* (PELLET omitted)	30.72	23	0.13	30.89	23	0.13	omitted		
Sample of existing homes	χ^2	df	$p > \chi^2$	χ^2	df	$p > \chi^2$	χ^2	df	$p > \chi^2$
Model *b1* (OIL-ST omitted)	omitted			19.56	27	0.85	16.87	27	0.93
Model *b2* (HEAT-P omitted)	15.84	27	0.96	omitted			27.58	27	0.43
Model *b3* (PELLET omitted)	13.25	27	0.99	28.56	27	0.38	omitted		
Sample of newly built homes				χ^2	df	$p > \chi^2$	χ^2	df	$p > \chi^2$
Model *b2* (HEAT-P omitted)				omitted			16.40	23	0.84
Model *b3* (PELLET omitted)				30.38	23	0.14	omitted		

H_0: Difference in coefficients of the reduced model *b* (one RHS is omitted) and full model *B* (all RHS included) not systematic. V(*b*-*B*) is estimated by V(*b*) – cov(*b*, *B*) – cov(*B*, *b*) + V(*B*). Reference category: GAS-ST. Note that OIL-ST is not included in the sample of newly built homes.

Table A2: LR tests for combining outcome categories

Categories tested	Full sample			Sample of existing homes			Sample of newly built homes		
	χ^2	df	$p > \chi^2$	χ^2	df	$p > \chi^2$	χ^2	df	$p > \chi^2$
GAS-ST - OIL-ST	267.97	22	0.000	461.85	26	0.000	OIL-ST not included		
GAS-ST - HEAT-P	813.74	22	0.000	434.14	26	0.000	470.78	22	0.000
GAS-ST - PELLET	1150.43	22	0.000	874.50	26	0.000	318.83	22	0.000
OIL-ST - HEAT-P	719.00	22	0.000	413.77	26	0.000	OIL-ST not included		
OIL-ST - PELLET	627.46	22	0.000	590.06	26	0.000	OIL-ST not included		
HEAT-P - PELLET	790.61	22	0.000	303.91	26	0.000	172.62	22	0.000

H_0: All coefficients except intercepts associated with given pair of outcomes are 0 (i.e. categories can be collapsed). Note that OIL-ST is not included in the sample of newly built homes.

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References

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 (also published as ZEW Discussion Paper 10-094). Available online: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1727279 .

AEE – Agentur für Erneuerbare Energien (2010), Bundesländervergleich Erneuerbare Energien, Zusammenfassung der Studienergebnisse. *Renews Spezial*, Ausgabe 44, November, [Online] Available at: http://www.unendlich-viel-energie.de/ uploads/media/44_Renews_Spezial_Bundeslaendervergleich_EE_2010_online.pdf [accessed March 14, 2011].

AGEB – Arbeitsgemeinschaft Energiebilanzen e.V. (2011), Anwendungsbilanzen für die Energiesektoren in Deutschland im Jahr 2008, Studie beauftragt vom Bundesministerium für Wirtschaft und Technologie, Projektnummer: 40/08, Berlin, 15. Februar 2011.

Banfi, S., Farsi, M., Filippini, M. and Jakob, M. (2008), Willingness to pay for energy-saving measures in residential buildings, *Energy Economics*, 30 (2), 503-516.

BDH - Bundesindustrieverband Deutschland Haus-, Energie- und Umwelttechnik e.V. (2009), Dynamischer Trend zu Effizienz und Erneuerbaren Energien im Heizungsbereich, [Online] Available at: http://www.bdh-koeln.de/html/pdf/pdf_presse/2009-01-26-praesentation-zur-pk.pdf [accessed March 14, 2011].

BDH - Bundesindustrieverband Deutschland Haus-, Energie- und Umwelttechnik e.V. (2010), Trends und Herausforderungen im Wärmemarkt, [Online] Available at: http://bdh-koeln.de/uploads/media/100126_bdh-pm-folien_pk.pdf [accessed March 14, 2011].

Becker, G.S. (1965), A theory of the allocation of time, *The Economic Journal*, 75 (299), 493-517.

Beyer, C., Hermelink, A., Klaus, S., Kleßmann, C., Krechting, A., Müller, A., and Palernberg, A. (2010), Innovative Politikmaßnahmen für mehr Energieeffizienz. Vorschlag für Politikmaßnahmen zur Steigerung der Energieeffizienz im Gebäudesektor in Deutschland bis 2020, Study commissioned by Verband der Chemischen Industrie e.V. [Online] Available at: http://www.ecofys.com/de/veroeffentlichungen/documents/Ecofys_VCI_ Politikmassnahmen_ Bericht_final_03_2011.pdf, [accessed March 14, 2011]

Biomasseatlas (2011), Biomasseatlas – Vertriebskompass für die Biomassebranche, [Online] Available at: http://www.biomasseatlas.de [accessed March 14, 2011].

BMU – Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (2007), The integrated energy and climate program of the German government, [Online] Available at: http://www.bmu.de/files/pdfs/allgemein/application/pdf/ hintergrund_meseberg_en.pdf [accessed March 14, 2011].

BMU – Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (2008), Heat from renewable energies. What will the new heat act achieve? [Online] Available at: http://www.erneuerbare-energien.de/files/pdfs/allgemein/ application/pdf/broschuere_waermegesetz_en.pdf [accessed March 14, 2011].

BMU – Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (2010), Jahr 2009 brachte Förderrekord bei Erneuerbaren Energien im Wärmebereich, Gemeinsame Pressemitteilung mit der KfW Bankengruppe Nr. 032/10, March 5, 2010 [Online] Available at: http://www.bmu.de/pressemitteilungen/aktuelle_pressemitteilungen/pm/ 45729.php [accessed November 30, 2011].

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

BSW – Bundesverband Solarwirtschaft e.V. (2011), Statistische Zahlen der deutschen Solarbranche (Solarthermie). Stand Januar 2011, [Online] Available at: http://www.solarwirtschaft.de/fileadmin/content_files/faktenblatt_st_jan11.pdf [accessed March 14, 2011].

BBSR - Bundesinstitut für Bau-, Stadt- und Raumforschung (2011a), Laufende Raumbeobachtung – Raumabgrenzungen. Zusammengefasste Kreistypen. [Online] Available at: http://www.bbsr.bund.de/cln_032/nn_103086/BBSR/DE/Raumbeobachtung/ Werkzeuge/Raumabgrenzungen/SiedlungsstrukturelleGebietstypen/Kreistypen__zus/Kreistypen__Zusamm.html [accessed November 23, 2011].

BBSR - Bundesinstitut für Bau-, Stadt- und Raumforschung (2011b), Indikatorenblatt - Wohnungsgröße - Laufende Bevölkerungsumfrage. [Online] Available at: http://www.bbsr.bund.de/cln_032/nn_84016/BBSR/DE/RBAlt/Komponenten/LaufendeBevoelkerungsumfrage/WohnungenWohnen/Wohnflaeche/Indikatorenblatt__2010,templateId=raw,property=publicationFile.pdf/Indikatorenblatt_2010.pdf [accessed November 23, 2011].

BBSR – Bundesinstitut für Bau-, Stadt- und Raumforschung (2011c), Laufende Raumbeobachtung – Raumabgrenzungen – Raumtypen 2010. [Online] Available at: http://www.bbsr.bund.de/cln_032/nn_1067638/BBSR/DE/Raumbeobachtung/Raumabgrenzungen/Raumtypen2010/raumtypen2010__node.html?__nnn=true [accessed November 23, 2011].

Bundesregierung (2010), Energiekonzept für eine umweltschonende, zuverlässige und bezahlbare Energieversorgung. 28. September 2010. [Online] Available at: http://www.bmu.de/files/pdfs/allgemein/application/pdf/energiekonzept_bundesregierung.pdf [accessed March 14, 2011].

Clausen, J. (2008), Feldvermessungsstudie Klimaschutzregion Hannover: Überblick über das Praxisfeld und die Fokusbereiche Solarthermie und Ökostrom im Rahmen des Forschungsprojekts WENKE^2, WENKE^2-Diskussions Papier 3/2008. [Online] Available at: http://www.fk2.uni-oldenburg.de/wenke2/download/FeldvermessungsstudieEnergie3-1.pdf [accessed November 23, 2011].

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.

Decker, T. (2010), *Verbraucherverhalten beim Kauf eines privaten Gebrauchsguts am Beispiel Heizung*, Straubing: Verlag Attenkofer.

Destatis – Statistisches Bundesamt Deutschland (2010a), Umweltnutzung und Wirtschaft, Tabellen zu den Umweltökonomischen Gesamtrechnungen, Teil 2: Energie, Rohstoffe, Wiesbaden: Destatis.

Destatis – Statistisches Bundesamt Deutschland (2010b), Umweltnutzung und Wirtschaft, Tabellen zu den Umweltökonomischen Gesamtrechnungen, Teil 3: Treibhausgase, Luftschadstoffe, Wiesbaden: Destatis.

Destatis – Statistisches Bundesamt Deutschland (2011a), Baugenehmigungen, Baufertigstellungen nach Gebäudeart - Lange Reihen bis 2010. Wiesbaden: Destatis.

Destatis – Statistisches Bundesamt Deutschland (2011b), Wohngebäude- und Wohnungsbestand – Stichtag 31.12.2009, Fortschreibung des Wohngebäude- und Wohnungsbestandes, Wiesbaden: Destatis.

Dillman, D. A. (2007), *Mail and Internet Surveys: The tailored design method*, 2nd edition, New York: John Wiley&Co.

Dubin, J.A. (1986), A nested logit model of space and water heat system choice, *Marketing Science*, 5 (2), 112-124.

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

EnergieMarktDaten (2011), Interaktive Karten zur Gasversorgung – Marktgebiete (Gas), [Online] Available at: http://www.energiemarktdaten.de/gas/default.aspx [accessed November 30, 2011].

Fernandez, V.P. (2001), Observable and unobservable determinants of replacement of home appliances, *Energy Economics*, 23 (3), 305-323.

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.

Hausman, J.A. and McFadden, D. (1984), Specification tests for the multinominal logit model, *Econometrica*, 52 (5), 1219-1240.

IE Leipzig - Leipziger Institut für Energie GmbH (2009), Vollkostenvergleich Heizsysteme 2009. Informationen für Verbraucher vom IE Leipzig, [Online] Available at: http://www.ie-leipzig.com/IE/Publikationen/Studien/IE_Vollkostenvergleich_%202009.pdf, [accessed November 30, 2011].

IWU – Institut Wohnen und Umwelt GmbH (2007), Basisdaten für Hochrechnungen mit der Deutschen Gebäudetypologie des IWU, [Online] Available at: http://www.iwu.de/fileadmin/user_upload/dateien/energie/klima_altbau/Flaechen_Gebaeudetypologie_07.pdf [accessed March 14, 2011].

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. Available online: http://papers.ssrn.com/sol3/Delivery.cfm/SSRN_ID1950577_code1494485.pdf?abstractid=1950577.

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

http://www.fichtner.de/pdf/MAP-Evaluationsbericht_2009.pdf, [accessed November 30, 2011].

Liao, H.-C., Chang, T.-F. (2002), Space-heating and water-heating energy demands of the aged in the US, *Energy Economics*, 24 (3), 267-284.

Madlener, R. and 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. Available online: http://papers.ssrn.com/sol3/Delivery.cfm/SSRN_ID1887030_code1494485.pdf?abstractid= 1887030.

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.

Mansur, K., Mendelsohn, R. and Morrison, W. (2008), Climate change adaptation: a study of fuel choice and consumption in the US energy sector, *Journal of Environmental Economics and Management*, 55 (2), 175-193.

MAP – Marktanreizprogramm (2009), Richtlinien zur Förderung von Maßnahmen zur Nutzung erneuerbarer Energien im Wärmemarkt Vom 20. Februar 2009. [Online] Available at: http://www.erneuerbare-energien-niedersachsen.de/downloads/ eewaermegrichtlinie.pdf [accessed November 30, 2011]

Matsukawa, I. and Ito, N. (1998), Household ownership of electric room air conditioners, *Energy Economics*, 20 (4), 375-387.

Michelsen, C.C. and 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. Available online: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1620520.

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

Nesbakken, R. (1999), Energy consumption for space heating: A discrete-continuous approach, *Scandinavian Journal of Economics*, 103 (1), 165-184.

Rehdanz, K. (2007), Determinants of residential space heating expenditures in Germany, *Energy Economics*, 29 (2), 167-182.

Rehdanz, K. and Stöwhase, S. (2008), Cost liability and residential space heating expenditures of welfare recipients in Germany, *Fiscal Studies*, 29 (3), 329-345.

Sardianou, E. (2008), Estimating space heating determinants: An analysis of Greek households, *Energy and Buildings*, 40 (6), 1084-1093.

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.

Schuler, A., Weber, C. and Fahl, U. (2000), Energy consumption for space heating of West-German households: empirical evidence, scenario projections and policy implications, *Energy Policy*, 28 (8), 877-894.

Sopha, B.M., Klöckner, C.A. and Hertwich, E.G. (2011), Adopter and non-adopters of wood pellet heating in Norway. *Biomass and Bioenergy*, 35 (1), 652-662.

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

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 Cointegation and Causality Analysis, FCN Working Paper No. 8/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, April.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

2008

Madlener R., Gao W., Neustadt I., Zweifel P. (2008). Promoting Renewable Electricity Generation in Imperfect Markets: Price vs. Quantity Policies, FCN Working Paper No. 1/2008, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, July (revised May 2009).

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

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

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

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

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