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

FCN Working Paper No. 4/2012

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June 2012

**Institute for Future Energy Consumer Needs and Behavior (FCN)**

School of Business and Economics / E.ON ERC

RWTH AACHEN UNIVERSITY

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This FCN Working Paper has also been published as ZEW Discussion Paper No. 12-042.

Publisher: Prof. Dr. Reinhard Madlener
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# Factors Influencing German House Owners' Preferences on Energy Retrofits

Martin Achtnicht* and Reinhard Madlener†

June 2012

**Abstract**

In this paper, we identify key drivers and barriers for the adoption of building energy retrofits in Germany, which is promoted by public policy as an important measure to address the future challenges of climate change and energy security. We analyze data from a 2009 survey of more than 400 owner-occupiers of single-family detached, semidetached, and row houses in Germany, that was conducted as a computer-assisted personal interview (CAPI). In the survey, respondents were asked directly for reasons for and against retrofitting their homes, but also faced a choice experiment involving different energy retrofit measures. Overall, both the descriptive and econometric results show that house owners who are able to afford it financially, for whom it is profitable, and for whom there is a favorable opportunity, are more likely to undertake energy retrofit activities. Based on an estimated mixed logit error component model, we also simulate the incentive effects of different policy options, such as public subsidies and energy tax increases.

*JEL classification:* C25, D12, Q40.

*Keywords:* Building energy retrofit; Choice experiment; Energy efficiency; Residential buildings.

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# 1 Introduction

Driven by the high energy demand for electricity, heating, and cooling, the building sector is a major consumer of fossil fuels and a major emitter of greenhouse gases (IEA, 2011). This holds particularly true for industrialized countries such as Germany, where, for example, almost one third of total energy supply is consumed in residential buildings, primarily for space and water heating. From a purely engineering perspective, the potential to reduce both Germany's fossil fuel use and greenhouse gas emissions by replacing old heating equipment and improving thermal insulation of the existing building stock is considerable. Between 1989 and 2006 less than 30% of all possible energy-efficient renovations were implemented in Germany's residential buildings built between 1900 and 1979 (BMVBS, 2007). And in spite of the increasing importance of renewable energy sources, almost every second residential heating system in Germany is fueled by natural gas, while approximately another three in ten use fuel oil (BMVBS, 2007). The German government seeks to exploit this potential in order to achieve its climate protection goals and to secure future energy supply. In addition to regulations that specify energy efficiency requirements for existing buildings being renovated or reconstructed, such as the Energy Savings Ordinance (EnEV), there are public funding programs in place that provide grants and low-interest loans for energy retrofitting activities. However, the political success in terms of raising the retrofit rate has been rather limited so far. This indicates that economic, technical, and behavioral factors influencing retrofit decisions are still not well understood and not properly addressed by current policy design.

In this paper, we analyze data from a 2009 survey of German house owners both descriptively and econometrically. The aim is to learn more about reasons and motivations that encourage house owners to carry out building energy retrofits as well as on barriers against such investments. The survey data include responses to a choice experiment involving energy retrofits for existing houses. We analyze them by using both standard and mixed logit regression of choice outcome on experimental attributes as well as individual and building characteristics. Based on the estimated mixed logit (error component) model, we simulate the incentive effects of different policy options, such as public subsidies for such measures and energy tax increases.

This paper, therefore, contributes to the existing literature on preferences on energy-saving measures in residential buildings. An early study by Cameron (1985) using individual household data from the U.S. focused on energy retrofits such as insulation and storm windows. Through simulations based on a fitted nested logit model, she found the demand for retrofits to be responsive to retrofit costs, relative energy prices, and income. More recently, some studies provided empirical evidence for Switzerland (Alberini et al., 2011; Banfi et al., 2008; Jakob, 2007, 2006). Jakob (2007) undertook a comprehensive analysis of drivers and barriers to retrofit decisions of single-family house owners using survey data. He found that energy-efficient renovations are driven to a large extent by technical (e.g., lifetime of façade or roof) and occasional factors (e.g., building or roof space extensions), rather than income, age, or education. Banfi et al. (2008) conducted a choice experiment with Swiss apartment tenants and house owners in order to study the willingness-to-pay (WTP) for energy-saving measures. In the experiment, respondents could choose between their actual situation and a hypothetical alternative differing in the level of insulation of windows and façade, the presence of a ventilation system, and the price (monthly rent for apartments, purchase price for houses). The obtained WTP estimates are relatively high, but do not differentiate between the various kinds of benefits of the considered energy-saving measures (i.e. cost savings, increases in comfort, and environmental benefits). However, in contrast to our study presented here, Banfi et al. (2008) did not include any socioeconomic variables in their final binary logit model, while the multinomial logit model used by Jakob (2007) lacks detailed information on the renovation alternatives themselves. The study that is most closely related to ours is that by Alberini et al. (2011), who surveyed Swiss owner-occupiers of single-family, semidetached, and row houses that had not been renovated since 1996. The choice sets used in their choice experiment contained two unlabeled energy retrofit alternatives and the status quo. They found those respondents who expect significant increases in oil prices and those who consider climate change as important reason for doing retrofits to be less likely to opt for the status-quo alternative. Socioeconomic variables, however, had no significant effect on respondents' choices.

Other studies concerning preferences for retrofit measures are available for Canada (Sadler, 2003), the Netherlands (Poortinga et al., 2003), South Korea (Kwak et al., 2010), and Sweden (Nair et al., 2010). And there are also a few German studies on this topic, mainly concerned with WTP (Achtnicht, 2011; Grösche and Vance, 2009). Using both standard and mixed logit specifications, Grösche and Vance (2009) analyzed revealed preference data from a sample of single-family house owners, and estimated the households' WTP per kWh saved. However, the costs and energy savings associated with the respective retrofit measure (i.e. roof insulation, façade insulation, windows replacement, heating equipment replacement, and combinations thereof) had not been directly observed, but rather had to be estimated by the authors. Therefore, engineering calculations as well as information on regional wages and material costs were employed. Achtnicht (2011) was the first to explicitly include environmental benefits of building energy retrofits in terms of $CO_2$ savings in a choice experiment study. Based on a fitted mixed logit model, he obtained considerable WTP estimates of German house owners for reducing $CO_2$ emissions. In this paper, we use data from the same survey, but focus on key drivers and barriers for the adoption of energy retrofits. Note that, in addition to the studies involving thermal insulation measures, there is also a related strand of literature that solely focuses on preferences on residential heating systems; see Michelsen and Madlener (2011) for an overview.

The remainder of the paper is structured as follows: Section 2 describes the survey data (2.1) and gives a brief theoretical background on the discrete choice models used for the analysis (2.2). The empirical results are presented in section 3, with the findings from the descriptive statistical analysis discussed in subsection 3.1, the parameter estimates in subsection 3.2, and the simulation results in subsection 3.3. The final section 4 summarizes and concludes.

# 2 Data and methods

## 2.1 Survey design

The data set analyzed in this paper consists of survey responses of more than 400 owner-occupiers of single-family detached, semidetached, and row houses in Germany;[1] it represents a subsample of a representative survey of German house-

[1] In the following, we will refer to them briefly as house owners or respondents. Note that the considered house types account for 59% of the total residential living space and 48% of the residential units in Germany (IWU, 2011).

holds undertaken in June 2009. The survey was carried out by the market research company GfK in two stages: after recruiting individuals with telephone interviews, they were visited at their homes for computer-assisted face-to-face interviews (CAPI method). During the telephone screening, the individuals had been explicitly asked whether they are involved in the household's energy-related decisions, such as the choice of electricity supplier or heating technology. Only those who affirmed such an involvement were finally recruited and interviewed. A summary of the sample statistics is given in Table 1. The interviews took about fifty to sixty minutes on average, and made use of a structured questionnaire. This contained mostly closed questions about attitudes towards the environment, the household's energy use, housing conditions, and socioeconomic and demographic information.

The centerpiece of the questionnaire was a choice experiment involving building energy retrofits. Respondents could either choose a modern heating system or an improved thermal insulation for their house. Note that neither the concrete energy source for the heating measure nor the part of the house for the insulation measure were specified in the experiment. Instead, respondents were asked to imagine the technology option they would like to have for their home. A fractional factorial design was employed, using the Sawtooth software, so that respondents faced 12 choice sets, each containing two alternatives. Both alternatives were described by seven attributes: acquisition costs; annual energy-saving potential; payback period; $CO_2$ savings; opinion of an independent energy adviser; public and/or private funding; and period of guarantee[2] (Table 2). The experiment was designed such that acquisition costs, energy-saving potential, and payback period could not be added up to another. While the energy-saving potential was customized and calculated with current energy prices only, the payback period also included a supposed energy price development.[3] For more details on the design of this choice experiment see Achtnicht (2011).

[2]Guarantee in this context means that for the given period of time the builder or contractor is obligated to remedy deficiencies free of charge. In the absence of a time limitation stipulated in the contractual agreement, it is regulated by the German Construction Contract Procedures (GCCP/VOB) that, for example, contractors are liable for defects of heating and insulation systems for at least two years.

[3]Respondents were informed about this context by the interviewer at the beginning of the experiment.

In the choice experiment, the basic task for respondents was to opt for their preferred energy retrofit measure. After each choice, the respondents were also asked whether they would actually carry out the chosen measure in their home or not. Importantly, unlike Achtnicht (2011), we consider these subsequent answers in our analysis, and thereby include a status-quo (or no-choice) alternative. This approach ensures better congruence with consumer theory and real-world choices (e.g., Hoyos, 2010; Hanley et al., 2001; Carson et al., 1994), and allows for calculating marginal effects of explanatory variables on the probability of undertaking energy retrofits.

## 2.2 Model specifications

To analyze the outcome of the choices econometrically, the use of discrete choice models is required. Such models owe their theoretical grounding in microeconomics especially to McFadden (1974) and his *random utility maximization* approach. In this framework, a utility $U_{nj}$ provided by an alternative $j$ to a person $n$ is assumed to be

$$U_{nj} = V_{nj} + \varepsilon_{nj}, \tag{1}$$

where $V_{nj} = V(x_{nj})$ is a deterministic (observed) utility component, depending on attributes of the alternative and demographics of the person $x_{nj}$, and $\varepsilon_{nj}$ is a (unobserved) stochastic component. According to the economic theory of utility-maximizing behavior, person $n$ chooses that alternative from the alternative set $\{1, \ldots, J\}$ which provides him with the greatest utility. Since utility is modeled as a random variable, however, only choice probabilities can be estimated. Depending on the assumptions made about the distribution of the random variables $\varepsilon_{nj}$ ($n = 1, \ldots, N; j = 1, \ldots, J$), different discrete choice models are defined.

In this paper, we use both a standard logit and a mixed logit model for the analysis. In standard logit models, the $\varepsilon_{nj}$ are independent and identically distributed with type I extreme value distribution. As we further assume $V$ to be linear in unknown parameters $\beta$, the probability that person $n$ chooses alternative $i$ then takes the following closed form (e.g., Train, 2003):

$$P_{ni} = \frac{\exp(\beta' x_{ni})}{\sum_{j=1}^{J} \exp(\beta' x_{nj})}. \tag{2}$$

Table 1: Summary of sample statistics

| Survey question | Percent ($N$=408) |
|---|---|
| Gender | |
| Male | 60.8 |
| Female | 39.2 |
| Age | |
| 24–35 | 5.4 |
| 36–45 | 22.0 |
| 46–55 | 28.9 |
| 56–65 | 22.5 |
| 66 and more | 21.2 |
| Education | |
| No school degree | 0.3 |
| Secondary modern school degree (“Hauptschulabschluss”) | 34.0 |
| Intermediate school degree (“Realschulabschluss”) | 39.2 |
| Academic high or technical secondary school degree (“Abitur” or “Fachabitur”) | 11.8 |
| University or college degree | 14.5 |
| Not stated | 0.3 |
| Household’s monthly net income | |
| Less than €1,000 | 4.7 |
| €1000–1499 | 10.3 |
| €1500–1999 | 15.0 |
| €2000–2499 | 19.4 |
| €2500–3499 | 18.9 |
| €3500 and more | 15.0 |
| Not stated | 16.9 |
| Children not older than 18 in household | 28.9 |
| Region | |
| Western Germany | 82.6 |
| Eastern Germany | 17.4 |
| Number of inhabitants | |
| 1–4999 | 30.4 |
| 5000–19,999 | 26.7 |
| 20,000–99,999 | 27.5 |
| 100,000–499,999 | 8.8 |
| 500,000 and more | 6.6 |
| House type | |
| Single-family detached house | 74.0 |
| Semidetached house | 14.2 |
| Row house | 11.8 |
| Year of completion | |
| Before 1948 | 22.6 |
| 1949–1978 | 32.8 |
| 1979–1986 | 13.7 |
| 1987–1990 | 7.1 |
| 1991–2000 | 14.2 |
| 2001–2009 | 9.6 |

Table 2: Attributes and attribute levels in the choice experiment

| Attribute | Measure | Levels |
| --- | --- | --- |
| Acquisition costs (including, if any, public and/or private funding) | Heating system<br>Insulation | €10,000, €20,000, €30,000<br>€10,000, €20,000, €30,000, €40,000 |
| Annual energy-saving potential at current energy prices (including fuel and electricity costs related to heating) | Heating system<br>Insulation | 25%, 50%, 75% of reference[a] (in €)<br>25%, 50%, 75% of reference[a] (in €) |
| Payback period (number of years after which the measure will pay off) | Heating system<br>Insulation | 10 years, 20 years, 30 years<br>10 years, 20 years, 30 years |
| $CO_2$ savings | Heating system<br>Insulation | 0%, 25%, 50%, 75%, 100%<br>25%, 50%, 75% |
| Opinion of an independent energy adviser | Heating system<br>Insulation | recommendable, *blank*<br>recommendable, *blank* |
| Public and/or private funding | Heating system<br>Insulation | Yes, No<br>Yes, No |
| Period of guarantee | Heating system<br>Insulation | 2 years, 5 years, 10 years<br>2 years, 5 years, 10 years |

[a] Current annual heating energy costs indicated by the respondent; if respondents did not know or did not state their fuel bill (15.6% of final regression sample), annual costs of €14 per square meter have been reasonably assumed.

Note that in our case there are three alternatives per choice set ($J = 3$): heating measure ($j = 1$), insulation measure ($j = 2$), and status quo or no measure ($j = 3$). The status quo is used as the base alternative; its deterministic utility $V_{n3}$ is therefore normalized to zero. The standard logit model is fitted by maximum likelihood estimation using Stata's `asclogit` command.

In our mixed logit specification, we include an additional error component $\mu_n d_j$, where $\mu_n$ is a normally distributed random term with zero mean, and $d_j$ a dummy variable that identifies the two retrofit measures (i.e. $d_j = 1$ if $j < 3$; 0 otherwise). Thereby, we allow the heating and insulation alternative to be correlated in unobserved factors. This relaxes the IIA assumption of standard logit, and thus might represent a more realistic substitution pattern, in particular in the presence of the status-quo alternative (e.g., Hess and Rose, 2009; Campbell et al., 2008; Scarpa et al., 2005). Under these assumptions the choice probability can be written as the integral of standard logit probabilities over all values of $\mu$, weighted by the density of $\mu$ (e.g., Brownstone and Train, 1999), i.e.

$$P_{ni} = \int \frac{\exp(\beta' x_{ni} + \mu d_i)}{\sum_{j=1}^{J} \exp(\beta' x_{nj} + \mu d_j)} \, \phi(\mu|0, \sigma) \, \mathrm{d}\mu, \tag{3}$$

where $\beta$ and $\sigma$ are the parameters to be estimated. As this integral cannot be solved analytically, it has to be approximated through simulation during the estimation process. We follow the suggestion by Hole (2007) and use Halton draws with 500 replications for the maximum simulated likelihood estimation using Stata's `mixlogit` command.

# 3 Results and discussion

## 3.1 Descriptive results

Before turning to the estimation results, let us first discuss drivers and barriers to energy retrofit measures, as they were identified by respondents in this survey. Respondents were provided with lists of possible reasons why they would or would not consider certain measures for their house, where multiple answers were allowed. The four most frequently stated drivers for investing in energy retrofits were high energy costs (65%), due renovations (46%), increases in comfort (37%), and environmental and climate protection (29%). On the other hand, the absence of need for heating system (65%) or building envelope renovations (62%), the lack of financial resources (59%), and uncertainty about the payback period (51%) constitute important barriers. When asked for their response to high heating energy costs, respondents indicated that they mainly reduce the room temperature (70%) or heating duration (69%). Investing in new heating equipment and improved thermal insulation is far less common. See Tables 3–5 for more details.

Overall, the descriptive results suggest that German house owners are willing to install a new heating system or building envelope insulation if the following requirements can be met: (1) one must be able to afford it financially; (2) it must be (perceived as) profitable in terms of energy cost savings and payback period; and (3) there must be a favorable opportunity, such as a heating system to be replaced or a building envelope due for renovation. Otherwise, (simple) behavioral changes in heat energy consumption remain the only response to increasing energy expenses. In order to gain a deeper understanding of what drives people to invest in building energy retrofits, we analyze the experimental choice data econometrically in the next section.

Table 3: General reasons for energy retrofit measures

| Reason | Percent ($N$=408) |
|---|---|
| High energy costs | 65.0 |
| Renovation is due in any case | 46.1 |
| Increasing comfort in my home | 37.3 |
| Environmental and climate protection | 28.7 |
| Subsidies for such measures | 27.5 |
| Increasing my home's market value | 25.7 |
| Higher independence from energy or fuel supplier | 25.0 |
| Grant of low interest rate credits for such measures | 20.3 |
| Expected future legal requirements | 16.7 |
| Current legal requirements | 14.2 |
| Attraction of modern technology | 7.4 |
| Positive image of such measures | 4.2 |
| Other reasons | 7.1 |
| Not stated | 4.7 |

Table 4: Personal barriers against certain energy retrofit measures

| Barrier | Applies | Does not apply | Not stated |
|---|---|---|---|
| A renovation of the heating system is not necessary. | 66.4 | 29.9 | 3.7 |
| A renovation of the building envelope is not necessary. | 61.5 | 35.3 | 3.2 |
| I am/we are lacking the financial resources. | 58.6 | 31.6 | 9.8 |
| I am not sure whether such measures will pay off. | 50.5 | 46.8 | 2.7 |
| My/our house is already energy-optimized. | 36.5 | 57.4 | 6.1 |
| Adequate credits are not available. | 35.3 | 48.0 | 16.7 |
| The funding structure is too complex. | 33.8 | 50.5 | 15.7 |
| Such long-term investments will not pay off at my age. | 30.6 | 67.2 | 2.2 |
| I am not familiar with the new technology. | 28.2 | 63.0 | 8.8 |
| My/our house is lacking space to store certain fuels. | 28.2 | 70.1 | 1.7 |
| I am apprehensive of too much dirt and stress. | 24.5 | 69.6 | 5.9 |
| I am lacking the information. | 22.3 | 71.3 | 6.4 |
| I am not sure how much longer I will live in this house. | 21.8 | 74.8 | 3.4 |
| I am lacking the time. | 21.6 | 71.1 | 7.4 |
| My/our house is lacking space to install the equipment for certain heating systems. | 18.1 | 78.4 | 3.4 |
| I am apprehensive of losses of comfort due to newly required insulation standards (e.g. moldiness or restrictions for ventilating rooms). | 13.0 | 80.4 | 6.6 |
| My spouse/domestic partner opposes. | 9.3 | 79.9 | 10.8 |
| Structural or technical conditions are against a refurbishment (e.g. listed building). | 8.3 | 87.8 | 3.9 |

All information in percent ($N$=408)

Table 5: Alternatives to reduce heating energy costs

| Alternative | I already do/did that | I would consider that | That's out of the question | Not stated |
|---|---|---|---|---|
| Reduction of room temperature in several rooms / all over the house | 69.6 | 16.7 | 13.2 | 0.5 |
| Reduction of heating duration in several rooms / all over the house | 68.6 | 20.1 | 10.8 | 0.5 |
| Increased use of secondary heating system (e.g. fireplace) | 32.6 | 31.1 | 31.4 | 4.9 |
| Investment in improved thermal insulation | 25.5 | 42.7 | 28.2 | 3.9 |
| Acquisition of more efficient heating system | 17.4 | 41.7 | 36.3 | 4.7 |
| Switch to another energy or fuel supplier | 15.9 | 44.6 | 34.1 | 5.4 |
| Acquisition of heating system using a cheaper energy source | 12.0 | 45.8 | 36.2 | 5.9 |

All information in percent ($N$=408)

## 3.2 Parameter estimation results

By applying both a standard logit and a mixed logit model to the choice data, we identify further factors that influence house owners' decisions. In order to capture (observed) taste heterogeneity we control for a rich set of individual and building characteristics. The final variable specification was determined with the aid of a standard logit model. The estimation results are summarized in Table 6.[4] Note that interaction terms regarding different energy-saving measures have to be interpreted with reference to the status quo, which is the base alternative and which was chosen in 61.6% of the cases (compared to 22.3% for heating and 16.1% for insulation).

Let us first discuss the estimated standard logit model and then comment on differences between this and the additionally estimated mixed logit model. The attributes used in the experiment all enter the choice model significantly with expected signs. We find that higher acquisition costs and longer payback periods have a negative effect on choice probabilities, whereas greater energy-saving potential, recommendations made by independent energy advisers, funding, and longer guarantee periods exert a positive influence. In terms of environmental benefits, we find that $CO_2$ savings enter the model significantly and positively

[4]Although we use repeated choice observations per respondent, the reported standard errors of the standard logit model are not adjusted for clustering. This is due to the fact that the fully specified model did not converge when accounting for correlated observations, and might understate the standard errors. However, when including only generic variables (i.e. the attributes of the alternatives) in the model, analyses gave similar results in terms of statistical significance, both if adjusting for clustering and if using only one choice observation per respondent.

signed for heating systems, but play no role when it comes to insulation (compared to the status quo). This is in line with Achtnicht (2011) who analyzed the same data set, but did not take into account the status-quo alternative. The alternative-specific constants (ASCs) for heating and insulation capture the average effect of all unobserved factors. Their positive signs indicate that non-included factors on average increase the retrofit measure's likelihood of being chosen.

We also find significant income effects on choices. Low-income households are less likely to invest in energy retrofits. Unfortunately, 17% of respondents did not answer the survey question on the household's monthly net income. In order not to lose too many observations, we identify those respondents with a dummy variable and let this interact with the ASCs. Those who did not state their income are also less likely to invest. This finding may suggest that low-income households in particular did not indicate their income, which is partly supported by responses to other closely related questions (e.g., in terms of employment) and by comparing the sample income shares with official income data from 2009.[5]

Eastern Germans (excluding citizens of Berlin) seem to be more price-sensitive than western Germans.[6] High acquisition costs thus constitute an even higher barrier for eastern Germans. Having controlled for price sensitivity and income, however, eastern Germans are more likely to change their status quo. This is indicated by the positive and significant interaction terms between the "East" dummy and the ASCs. This result is somewhat surprising, given that, at least in terms of apartment buildings, houses in the east (and the south) of Germany are more energy-efficient as their counterparts in the northwest.[7] On the other hand, taking all residential buildings together, the building stock in eastern Germany is on average older than that in western Germany (Destatis, 2008). Hence, it remains unclear whether this finding reflects some kind of backlog demand in terms of building retrofits or a general willingness to further invest in energy-efficiency

[5] Note, however, that only house owners were surveyed who are arguably older and richer than the representative sample on which the official income statistics are based.

[6] Interestingly, Brosig-Koch et al. (2011) recently found that twenty years after reunification there are still significant differences in social behavior between eastern and western Germans. In their solidarity experiment, eastern German students were willing to hand over smaller amounts of money to potential losers than other students.

[7] Results from the energy-efficiency index by ista/IWH, which is based on energy consumption data from almost three million apartments in 312,000 buildings, not including single-family, semidetached, and row houses (http://www.iwh-halle.de/projects/2010/ista/d/download.asp).

improvements due to already experienced benefits.[8]

The respondent's age enters the model significantly. The older the house owner, the lower the likelihood of retrofit activities. We also control for both formal education and particular climate change knowledge. The literature provides evidence that not only formal education (specified by levels, degrees, or number of years), but also informal education can be influential when it comes to environment-related decisions (e.g., Torgler et al., 2009; Torgler and García-Valiñas, 2007; Carlsson and Johansson-Stenman, 2000; Danielson et al., 1995). In this study, we use the highest school degree obtained to measure a respondent's formal education, and identify those with an academic high school, technical secondary school, college, or university degree with a dummy variable. In order to determine a respondent's climate change knowledge we asked for the most important drivers of climate change. Thereby, respondents were provided with a list of six possible options, including the "don't know" option, and multiple answers were allowed.[9] The associated dummy variable takes the value 1 if both greenhouse gas emissions and rainforest deforestation, but not the ozone hole, were cited as reasons for climate change (24.3%). We find that better educated house owners and those with good knowledge about causes of climate change are more likely to select the insulation alternative. In terms of heating systems no statistically significant differences could be observed.

Besides these demographic and socioeconomic variables, we also include information on the building and its heating system in the model. The results match a priori expectations. Owners of houses that were built after 1990 (24%), or owners who saw no need to improve the thermal insulation (24%), are less likely to invest in energy retrofits. The retrofit of the heating system is even less likely if it is relatively new (33% installed it after the year 2000). If, however, the heating system is oil-fired (42.1%), then a heating retrofit becomes more attractive. This finding is arguably driven by the peak in the oil price in summer 2008, less than one year before the survey was conducted. In general, we find that fuel price expectations play an important role in investing in energy-saving measures. House owners who

[8]Nair et al. (2010) provide some evidence for the Swedish case that house owners are more likely to invest in retrofit measures if they replaced a building envelope component in the recent past.

[9]The answering options were "changes in solar activity" (15.2%), "increased emissions of greenhouse gases" (77.0%), "deforestation of the rainforest" (71.3%), "the hole in the ozone layer" (58.6%), "other reason" (14.7%), and "don't know" (2.0%).

expect the price of their heating fuel to increase strongly in the next ten years (40.4%) are more willing to change the energy-related status quo of their homes.

Next, we turn to the estimated mixed logit model in order to see how it differs from the estimated standard logit model. First and foremost, we find the error component specification to perform better than the standard logit one; a likelihood-ratio test reveals that the model fit is improved significantly ($\chi^2(1) = 1716.79$). The relatively large increase in the log likelihood, however, is mainly due to the fact that here, unlike in the standard logit specification, we account for repeated choices per respondent. The error component itself enters the choice model significantly, indicating correlation in the unobserved portion of utility between the two retrofit measures. This leads to increased substitution between the heating and the insulation measure. This means that, for instance, improvements in the heating alternative would attract disproportionately more house owners who previously would have selected the insulation alternative than those who opted for the status quo. In terms of the observed variables, we obtain consistent results here, although the statistical significance of some individual-specific variables is reduced. In addition, it should be noted that the general increase in magnitude of estimated parameters compared to the standard logit model is expected due to the different scale of utility (Brownstone and Train, 1999).

Overall, the econometric results do support the descriptive findings and put them on a firmer basis. Evidently, house owners who are able to afford it financially (e.g., costs, income), for whom it is profitable (e.g., energy-saving potential, payback period, age), and for whom there is a favorable opportunity (e.g., house age, heating age) are more likely to undertake retrofit activities. In addition, we find that place of residence, education, and specific climate change knowledge also influence retrofit decisions in a significant manner.

## 3.3 Simulation results

The computation of (average) marginal effects is usually a convenient way to summarize regression results and to illustrate the policy relevance of variables. However, a common problem with data from choice experiments is that the observations are based on hypothetical alternatives rather than real-world choice sets. Averages of experimental attribute levels thus do not reflect any meaningful reference point.

Table 6: The estimated models

| | Standard logit | | Mixed logit | |
|---|---|---|---|---|
| | Estimate | Std. err. | Estimate | Std. err. |
| *Variables* | | | | |
| Acquisition costs (in €1000) | −0.0540*** | (0.0030) | −0.0696*** | (0.0036) |
| Acquisition costs (in €1000) × East (dummy) | −0.0226*** | (0.0075) | −0.0290*** | (0.0091) |
| Energy-saving potential (in €1000/year) | 0.4297*** | (0.0638) | 0.6501*** | (0.0911) |
| Payback period (in years) | −0.0211*** | (0.0033) | −0.0249*** | (0.0037) |
| $CO_2$ savings (in %) × Heating (ASC) | 0.0066*** | (0.0009) | 0.0091*** | (0.0010) |
| $CO_2$ savings (in %) × Insulation (ASC) | −0.0006 | (0.0021) | 0.0001 | (0.0024) |
| Energy adviser (dummy; 1 for "recommendable") | 0.1926*** | (0.0513) | 0.2296*** | (0.0555) |
| Funding (dummy; 1 for "yes") | 0.2509*** | (0.0515) | 0.2972*** | (0.0558) |
| Guarantee period (in years) | 0.0251*** | (0.0081) | 0.0296*** | (0.0091) |
| Heating system (ASC relative to status quo) | 0.5658** | (0.2397) | 1.5369* | (0.8934) |
| Insulation system (ASC relative to status quo) | 0.5845** | (0.2854) | 1.7286* | (0.9103) |
| East (dummy) × Heating (ASC) | 0.7446*** | (0.1676) | 1.0789** | (0.4780) |
| East (dummy) × Insulation (ASC) | 0.4875** | (0.2089) | 0.7398 | (0.5021) |
| Income below €2000 (dummy) × Heating (ASC) | −0.6169*** | (0.0100) | −1.2890*** | (0.4085) |
| Income below €2000 (dummy) × Insulation (ASC) | −0.5128*** | (0.1079) | −1.1515*** | (0.4105) |
| Income missing (dummy) × Heating (ASC) | −0.3141*** | (0.1116) | −0.8270* | (0.4729) |
| Income missing (dummy) × Insulation (ASC) | −0.8179*** | (0.1374) | −1.2829*** | (0.4800) |
| Age (in years) × Heating (ASC) | −0.0209*** | (0.0034) | −0.0410*** | (0.0142) |
| Age (in years) × Insulation (ASC) | −0.0078** | (0.0038) | −0.0271* | (0.0143) |
| Education (dummy) × Heating (ASC) | −0.0102 | (0.0912) | 0.0627 | (0.3872) |
| Education (dummy) × Insulation (ASC) | 0.1890* | (0.1018) | 0.2436 | (0.3904) |
| Climate change knowledge (dummy) × Heating (ASC) | 0.1083 | (0.0911) | 0.1835 | (0.3844) |
| Climate change knowledge (dummy) × Insulation (ASC) | 0.2917*** | (0.1000) | 0.5099 | (0.3866) |
| House built after 1990 (dummy) × Heating (ASC) | −0.2335** | (0.0984) | −0.5461 | (0.4235) |
| House built after 1990 (dummy) × Insulation (ASC) | −0.3620*** | (0.1148) | −0.7731* | (0.4289) |
| State of insulation (dummy) × Heating (ASC) | −0.2007** | (0.0955) | −0.7685* | (0.4070) |
| State of insulation (dummy) × Insulation (ASC) | −0.9213*** | (0.1217) | −1.5597*** | (0.4155) |
| Heating installed after 2000 (dummy) × Heating (ASC) | −0.2253** | (0.0902) | −0.3781 | (0.3699) |
| Heating installed after 2000 (dummy) × Insulation (ASC) | 0.2821*** | (0.0976) | 0.2395 | (0.3718) |
| Oil-fired heating (dummy) × Heating (ASC) | 0.2372*** | (0.0816) | 0.3513 | (0.3453) |
| Oil-fired heating (dummy) × Insulation (ASC) | −0.0427 | (0.0924) | −0.0389 | (0.3486) |
| Price expectations (dummy) × Heating (ASC) | 0.3310*** | (0.0793) | 0.4944 | (0.3387) |
| Price expectations (dummy) × Insulation (ASC) | 0.1632* | (0.0901) | 0.3705 | (0.3420) |
| *Error components* | | | | |
| Retrofit measure | | | 2.8505*** | (0.1717) |
| Persons | 379 | | 379 | |
| Observed choices | 4548 | | 4548 | |
| Log likelihood | -3768.1 | | -2909.8 | |
| McFadden's Pseudo $R^2$ | 0.246 | | 0.418 | |

Asterisks denote statistical significance at the *** $p< 0.01$, ** $p< 0.05$, and * $p< 0.1$ level.

Nonetheless, it is interesting to see how a small change in a regressor affects the predicted choice probabilities. Therefore, we define a baseline scenario where we use specific values for the experimental attributes, but leave all other variables at their sample values. Starting from this, we compute the effect of a one-unit change in a regressor for each case, holding all other variables equal, and then average the individual effects. For dummy variables, we compute the effect of a discrete change from zero to one. To take account of the correlation in unobserved factors between both retrofit measures, and thereby relax the IIA property of the standard logit model, we use the mixed logit error component specification here. Table 7 presents the results of this simulation in detail.

In our baseline scenario, we consider a hypothetical situation in which both heating and insulation alternatives are equal in cost (€20,000), achieve the same energy-cost (50% of current heating costs)[10] and $CO_2$ savings (50%), and have the same payback (15 years) and guarantee periods (2 years). Also, we assume that neither funding from private or public sources nor expert recommendations from independent energy advisers are available. Based on the estimated mixed logit model, the status-quo alternative would have by far the highest probability of being chosen in such a situation (58.9%), followed by insulation (27.5%) and heating measures (13.6%). The result that, on average, insulation measures are preferred compared to heating measures could be due to ancillary benefits of insulation, such as maintaining a cool home during summer and increased noise protection (see Jakob, 2006, for a discussion on the role of co-benefits of thermal insulation measures in retrofit decisions).

In the scenarios 1–5, we consider how outcome probabilities respond to one-unit improvements in selected attributes of both energy-saving measures. Although the status quo remains the dominant choice of house owners in each scenario, statistically significant changes can be observed. These changes can be interpreted as the incentive effects of different policy options, such as public subsidies and energy tax increases. It should be noted, however, that the magnitude of the effects depends on the point of evaluation as well as the scale of the variable of interest. Since the energy-saving potential is measured in €1000 per year,

[10] In the final regression sample, 50% of current annual heating costs are distributed as follows: Mean = 0.71; Standard Deviation = 0.32; Minimum = 0.10; Maximum = 2.00 (all values are reported in €1000/year).

Table 7: The simulated average choice probabilities and effects

| Scenario | Definition | Heating | Insulation | Status quo |
|---|---|---|---|---|
| Baseline | Hypothetical values for heating and insulation attributes: costs = 20, energy savings = 50% of reference, payback period = 15, $CO_2$ savings = 50, energy adviser = 0, funding = 0, guarantee period = 2; sample values for all other variables | 13.6 | 27.5 | 58.9 |
| 1 | Same as baseline, but with costs - 1 | +0.3 | +0.6 | −0.8 |
| 2 | Same as baseline, but with energy savings + 0.1 | +0.2 | +0.5 | −0.7 |
| 3 | Same as baseline, but with payback period - 1 | +0.1 | +0.2 | −0.3 |
| 4 | Same as baseline, but with energy adviser = 1 | +0.9 | +1.7 | −2.6 |
| 5 | Same as baseline, but with funding = 1 | +1.1 | +2.2 | −3.3 |

All estimates are statistically significant at the $p < 0.01$ level.

for example, we consider an increase of only 0.1 units (i.e. €100) in scenario 2. In scenario 1, we see that a €1000 reduction in acquisition costs raises the likelihood of energy retrofits by 0.8 percentage points compared to the baseline. But this, of course, predicts only the isolated, *ceteris paribus* effect of such a cost reduction. In reality, lower costs imply shorter payback periods that may also be the result of some sort of funding, which further make energy retrofits more likely (see scenarios 3 and 5). Similar considerations apply to higher energy-cost savings, which, taken by themselves, raise the likelihood of energy retrofits by 0.7 percentage points (scenario 2). Scenario 4 reveals the notable effect that the opinion of an independent energy adviser has upon a house owner's decision-making. Compared to the baseline scenario, the choice probability for the status-quo alternative decreases by 2.6 percentage points if we assume that both energy-saving measures are recommended by an expert.

# 4 Summary and conclusion

In this paper, we identified key drivers and barriers for the adoption of building energy retrofits in Germany, which is promoted by public policy as an important measure to address the future challenges of climate change and energy security. We analyzed data from a 2009 survey of more than 400 owner-occupiers of single-family detached, semidetached, and row houses in Germany, that was conducted as a computer-assisted personal interview (CAPI). In the survey, respondents were asked directly for reasons for and against retrofitting their homes, but also faced a choice experiment involving different energy retrofit measures. Overall, both the descriptive and econometric results show that house owners who are able to afford it financially, for whom it is (or who perceive it as) profitable in terms of energy cost savings and payback period, and for whom there is a favorable opportunity, such as a heating system that needs replacement or a building envelope that is due for renovation, are more likely to undertake energy retrofit activities.

The latter point seems to be of particular importance in order to explain the persistent low retrofit rate of around 1% in Germany. Our results suggest that most house owners wait until building components are approaching the end of their useful life, before considering options for renovation or replacement (Jakob, 2007, came to a similar conclusion for the Swiss case). Once such an opportunity occurs, they assess whether or not the additional costs for energy efficiency improvements are affordable and profitable. This behavior can be viewed as rational from the house owner's perspective.

Given this, the crucial question now is how to stimulate building energy retrofits, and thereby reduce the energy consumption and $CO_2$ emissions of existing buildings, in an effective and cost-efficient way. German regulations in force prescribe certain energy-efficiency standards for buildings being renovated or reconstructed. But standards usually fail to meet the cost-efficiency criteria (e.g., Kolstad, 2000; Hahn and Stavins, 1991), and lack a dynamic incentive for house owners to undertake (cost-efficient) measures beyond the existing energy efficiency standard. We used the estimated model to simulate the incentive effects of other conceivable policy options. Public subsidies or other forms of financial support lower the costs of energy retrofits for individual house owners and thus make them more likely to be chosen. However, free-rider problems generally jeopardize the efficiency of funding measures (see Grösche and Vance, 2009, for some German evidence). On the other hand, an energy tax increase makes energy retrofits also more beneficial for house owners, but raises issues of distributional justice that must be addressed.

Professional energy advice seems to be a promising option in helping to achieve the aforementioned goals of effectiveness and cost efficiency. The incentive effect of expert recommendations that we found in our stated preference setting was notable in magnitude. Also, from a theoretical economic perspective, it is preferable to have decisions that are based on reliable and accurate information. Imperfect information and transaction costs constitute important barriers to investments in energy-efficient technologies in the real world (e.g., Howarth and Andersson, 1993), but were abstracted in the choice experiment analyzed here. Increased use of energy advisory services may help to alleviate the problem of imperfect information on the part of consumers. It seems, therefore, recommendable to support independent energy advice by public funding.[11,12] However, an important task for future research will be to confirm its effectiveness and to examine potential free rider issues using real-world field data.

[11]Such programs exist, for example, in the federal state of Baden-Wuerttemberg. There, the Ministry of Environment cooperates with different partners from the fields of crafts, architecture, and engineering within the project "EnergieSparCheck" in order to provide house owners with information on the energy requirement of their homes and potential energy-saving measures.

[12]Research on the role of energy audits in the residential household sector is still very rare. Anderson and Newell (2004) found a high responsiveness of U.S. manufacturers to government-sponsored energy audits in terms of energy-efficient technology adoption.

# References


Achtnicht, M. (2011), Do environmental benefits matter? Evidence from a choice experiment among house owners in Germany, *Ecological Economics* 70(11), 2191–2200.

Alberini, A., Banfi, S., Ramseier, C. (2011), *Energy efficiency investments in the home: Swiss homeowners and expectations about future energy prices*, Working paper series 11–80, Center for Energy Policy and Economics (CEPE), ETH Zurich.

Anderson, S.T., Newell, R.G. (2004), Information programs for technology adoption: The case of energy-efficiency audits, *Resource and Energy Economics* 26(1), 27–50.

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

BMVBS (Federal Ministry of Transport, Building and Urban Development) (2007), *$CO_2$ Gebäudereport 2007*, Federal Ministry of Transport, Building and Urban Development, Berlin.

Brosig-Koch, J., Helbach, C., Ockenfels, A., Weimann, J. (2011), Still different after all these years: Solidarity behavior in East and West Germany, *Journal of Public Economics* 95(11–12), 1373–1376.

Brownstone, D., Train, K. (1999), Forecasting new product penetration with flexible substitution patterns, *Journal of Econometrics* 89(1–2), 109–129.

Cameron, T.A. (1985), A nested logit model for energy conservation activity by owners of existing single family dwellings, *The Review of Economics and Statistics* 67(2), 205–211.

Campbell, D., Hutchinson, W.G., Scarpa, R. (2008), Incorporating discontinuous preferences into the analysis of discrete choice experiments, *Environmental and Resource Economics* 41(3), 401–417.

Carlsson, F., Johansson-Stenman, O. (2000), Willingness to pay for improved air quality in Sweden, *Applied Economics* 32(6), 661–669.

Carson, R.T., Louviere, J.J., Anderson, D.A., Arabie, P., Bunch, D.S., Hensher, D.A., Johnson, R.M., Kuhfeld, W.F., Steinberg, D., Swait, J., Timmermans, H., Wiley, J.B. (1994), Experimental analysis of choice, *Marketing Letters* 5(4), 351–368.

Danielson, L., Hoban, T.J., Van Houtven, G., Whitehead, J.C. (1995), Measuring the benefits of local public goods: Environmental quality in Gaston County, North Carolina, *Applied Economics* 27(12), 1253–1260.

Destatis (Federal Bureau of Statistics) (2008), *Wohnsituation in Deutschland 2006*, Federal Bureau of Statistics, Wiesbaden.

Grösche, P., Vance, C. (2009), Willingness-to-pay for energy conservation and free-ridership on subsidization – Evidence from Germany, *The Energy Journal* 30(2), 135–154.

Hahn, R.W., Stavins, R.N. (1991), Incentive-based environmental innovation: A new era from an old idea?, *Ecology Law Quarterly* 18(1), 1–42.

Hanley, N., Mourato, S., Wright, R.E. (2001), Choice modelling approaches: A superior alternative for environmental valuation?, *Journal of Economic Surveys* 15(3), 435–462.

Hess, S., Rose, J.M. (2009), Should reference alternatives in pivot design SC surveys be treated differently?, *Environmental and Resource Economics* 42(3), 297–317.

Hole, A.R. (2007), Fitting mixed logit models by using maximum simulated likelihood, *The Stata Journal* 7(3), 388–401.

Howarth, R.B., Andersson, B. (1993), Market barriers to energy efficiency, *Energy Economics* 15(4), 262–272.

Hoyos, D. (2010), The state of the art of environmental valuation with discrete choice experiments, *Ecological Economics* 69(8), 1595–1603.

IEA (International Energy Agency) (2011), *World Energy Outlook 2011*, OECD/IEA, Paris.

IWU (Institut Wohnen und Umwelt) (2011), *Basisdaten für Hochrechnungen mit der Deutschen Gebäudetypologie des IWU*, Darmstadt.
URL: http://www.iwu.de/fileadmin/user_upload/dateien/energie/klima_altbau/Flaechen_Gebaeudetypologie_Aug_2011.pdf (accessed on: 22 May 2012).

Jakob, M. (2006), Marginal costs and co-benefits of energy efficiency investments – The case of the Swiss residential sector, *Energy Policy* 34(2), 172–187.

Jakob, M. (2007), *The drivers of and barriers to energy efficiency in renovation decisions of single-family home-owners*, Working paper series 07–56, Center for Energy Policy and Economics (CEPE), ETH Zurich.

Kolstad, C.D. (2000), *Environmental Economics*, Oxford University Press, New York.

Kwak, S.-Y., Yoo, S.-H., Kwak, S.-J. (2010), Valuing energy-saving measures in residential buildings: A choice experiment study, *Energy Policy* 38(1), 673–677.

McFadden, D. (1974), Conditional logit analysis of qualitative choice behavior. In: Zarembka, P. (Ed.), *Frontiers in Econometrics*, Academic Press, New York, pp. 105–142.

Michelsen, C.C., Madlener, R. (2011), Homeowners' preferences for adopting residential heating systems: A discrete choice analysis for Germany, *Energy Economics* (forthcoming).

Nair, G., Gustavsson, L., Mahapatra, K. (2010), Factors influencing energy efficiency investments in existing Swedish residential buildings, *Energy Policy* 38(6), 2956–2963.

Poortinga, W., Steg, L., Vlek, C., Wiersma, G. (2003), Household preferences for energy-saving measures: A conjoint analysis, *Journal of Economic Psychology* 24(1), 49–64.

Sadler, M. (2003), *Home energy preferences and policy: Applying stated choice modeling to a hybrid energy economic model*, Report to Natural Resources Canada, Simon Fraser University.

Scarpa, R., Ferrini, S., Willis, K.G. (2005), Performance of error component models for status-quo effects in choice experiments. In: Scarpa, R., Alberini, A. (Eds.), *Applications of Simulation Methods in Environmental and Resource Economics*, Springer, Dordrecht.

Torgler, B., Frey, B., Wilson, C. (2009), Environmental and pro-social norms: Evidence on littering, *The B.E. Journal of Economic Analysis & Policy: Topics* 9(1), 1–39.

Torgler, B., García-Valiñas, M.A. (2007), The determinants of individuals' attitudes towards preventing environmental damage, *Ecological Economics* 63(2–3), 536–552.

Train, K.E. (2003), *Discrete Choice Methods with Simulation*, Cambridge University Press, Cambridge.

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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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