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Abstract

The rapid diffusion of distributed power generation systems has given rise to "energy-prosumers", or energy-producing consumers. These actors are key components in the energy transition of many countries where they are about to undermine long-established value creation mechanisms in the energy sector. In this paper, we investigate drivers of prosumption and possible solutions to the market share losses recently experienced by incumbent energy companies. In doing so, we focus on residential consumers' preferences for service innovations related to the usage of photovoltaic (PV) systems with storage, such as system control and maintenance, duration of the supply contract, and channels of purchase and installation. We investigate these service innovations along the four lines of novelty, complementarity, efficiency, and lock-in, key aspects of innovative value creation mechanisms. Our case study is the Italian market, where residential PV systems are already widespread but decentralized energy storage devices are not. For the investigation, we designed a discrete choice experiment conducted among both PV system owners and knowledgeable non-adopters. The estimation results, based on the Hierarchical Bayes technique, provide interesting new insights regarding the viability of the "rent-a-roof" model as a cooperation strategy between consumers and utility companies to counteract the disruptive effect of PV systems with storage.

JEL Classification: C9, D1, O3, Q4

Keywords: Consumer preferences; Hierarchical Bayes; Residential PV; Energy storage; Italian energy market

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1 Introduction

In recent years and liberalized markets, incumbent electricity utility companies have been losing market shares, jeopardizing the traditional electricity supply paradigm (Sioshansi, 2014). Major drivers of this paradigm shift are the ambitious renewable energy policy targets and generous supports for the adoption of small-scale residential photovoltaic (PV) systems that led to a boom in the adoption of decentralized conversion and storage systems. PV systems have the potential to be disruptive technologies (Islam, 2014; Christensen, 1997), as they affect the market dynamics involving incumbent energy utility companies (Frantzis et al., 2008). The disruptive effects are linked to the rise of a new market player, the *prosumer*. In the energy context, "prosumption" indicates a consumer who self-generates electricity for self-consumption. The rise of this new actor begs the question what role and position of each actor in the market of the decentralized energy system will be (Richter, 2013; Schoettl and Lehmann-Ortega, 2011).

As illustrated in Sauter and Watson (2007) and Watson (2004), the level of prosumption depends on the actor owning and operating the system. The authors introduce several options for the integration of PV systems: firstly, when the system is owned and operated by the residential household ("Plug-and-Play" model) and no electricity is fed into the grid, then the highest level of self-consumption (and therefore prosumption) is achieved. Secondly, within a "Community micro-grid", households can benefit from a better local balance between supply and demand of the electricity generated. Thirdly, more and more often utilities will have to deal with components not owned by them; under the "Company control" scheme the ownership of the technology remains in the hands of the households but the company has the ability to operate the decentralized capacity in a virtual power plant (VPP). Finally, some alternatives might even foresee third-party ownership of the system – as described by Frantzis et al. (2008) in their "rent-a-roof" scheme – to offer intermediate solutions characterized by a fair sharing of risk and benefits between consumers and producers. In addition, utility companies put in place a number of short-term strategies to solve the problem represented by prosumers currently underpaying for the provision of balancing services (Wood and Borlick, 2013). Carlsson and Martinsson (2008) suggest that households that invested in a PV system still value the provision of traditional grid services as a back-up option to their in-house system positively even if they have to pay higher fixed costs for these. Long-term solutions relying on the integration of decentralized PV systems into the utility through its direct involvement in community solar projects were presented by Blansfield and Jones (2014). By focusing on value generation, we argue that a partnership between consumers and the utility based on renting the roof, is a valid alternative to the strategies suggested above to cope with the disruptive character of PV systems.

Value creation is at the core of any market transaction. In traditional transactions between companies and consumers in the electricity market, value is generated on the supply side thanks to the provision of electricity (revenues from selling electricity). While the manufacturing sector has for a long time been familiar with the concept of co-construction (Udwadia and Kumar, 1991), consumer integration in the value chain of the energy industry was an unknown phenomenon until recently. An early investigation of consumers' participation through electricity co-provision was undertaken by van Vliet (2003). Co-provision affects the way consumers value the traditional services provided by utility companies, thus contributing to a shift in the perception of electricity from a mere good to a service (Vargo and Lusch, 2004). Within this service-dominant logic, the central role of energy utilities becomes that of an energy service company, in the co-creation of whose services the consumer is actively involved. A key element of the decentralized energy system is the level of innovativeness of the services provided by the company (Watson et al., 2006); examples include consulting, installation, and financing (Richter, 2012). Like any innovation, the success of new services and the consequent integration of consumers in the value chain depends on companies' ability to convince them of the value delivered (Shomali and Pinkse, 2016).

In our study, based on the conceptual framework of value creation and prosumption theory, we designed a DCE to identify which innovative services offered by energy utility companies are more likely to divert consumers interested in PV systems away from prosumption. In doing so, we explore future dynamics of the Italian electricity market.

Since the introduction of the First Energy Incentive Plan (Primo Conto Energia, CE1) in 2005, the diffusion of small-scale PV systems in Italy (capacity < 20 kW) has rapidly risen to achieve about 3,500 MW of installed capacity at the end of 2015 (Gestore Servizi Energetici, 2015). In 2010 the price of electricity purchased from the grid at the residential tariff reached the levelized cost of electricity (LCOE) self-produced by PV systems without storage, (Breyer and Gerlach, 2013) a phenomenon known as "grid parity". This was followed in 2012 by the implementation of the last incentivizing scheme that ended in July 2013. Energy utilities may become major players in pushing the diffusion of such disruptive technologies further; in fact, despite electricity retail prices above the European average (Eurostat, 2015), the diffusion of PV system in Italy is currently stagnating (Palmer et al., 2015) due to policy-makers uneager to incentivize new PV systems through feed-in tariffs (FiT) and a demand-side split between a significant share of prosumers and a mass of inert consumers.

In light of the widespread adoption of residential PV systems in Italy it is of paramount importance to consider battery storage devices as an alternative to the popular net metering contracts; in fact, this technology yields value to a segment of consumers with flexible electricity self-consumption, at the same time enabling the energy transformation of the country towards renewables and decarbonization (Colmenar-Santos et al., 2012; Hoppmann et al., 2014).[1] Discrete Choice Experiments (DCEs) are the best methodology to gain insights into consumers' preferences for innovative services linked to the deployment of technologies not yet spread in the market, as is the case for decentralized energy storage devices. Using this survey methodology, Amador et al. (2013) investigated drivers of electricity supplier choice while Ida et al. (2014), Islam and Meade (2013), and Scarpa and Willis (2010) looked into motivations and preferences for PV systems. Still, it remains unclear whether consumers would still "prosume" if there were alternatives available in the market, e.g. the roof-rental one; in this first of its kind work, we explore the conditions under which consumers decide to engage in a partnership with utility

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[1] Starting from January 2015, the Italian government has allowed the installation of decentralized batteries in order to increase the share of self-consumption at the household level. However, the current Italian regulatory framework does not allow either arbitrage or the provision of ancillary services (Energy & Strategy Group, 2013).

companies or – if already owning a PV system – give up the control of it rather than prosuming.

The econometric estimation of Hierarchical Bayes logit models reveals credible preferences in favor of PV systems with battery storage facilities controlled and owned by the utility, which is in line with the "rent-a-roof" model. Furthermore, battery storage is well accepted as long as it comes at no additional cost. Solutions characterized by household ownership of the system but subsidized investment costs are also positively valued by respondents as a viable alternative. MANOVA analysis confirms differences in preferences between PV adopters and knowledgeable non-adopters. Finally, sensitivity analysis confirms the importance of system control, investment costs, and inclusion of a battery storage in the PV investment decision.

The remainder of this paper is organized as follows. Section 2 contains our research hypotheses, the theoretical background embraced to inform them, and a description of the survey methodology adopted to test them. The choice data gathered this way were analyzed following the Bayesian approach. Strengths and weaknesses of the econometric estimation are discussed in section 3, which also reports on the estimation results. Section 4 offers some conclusions and policy recommendations.

2 Methodology

2.1 The research hypotheses

We build on existing theories of value creation to explain preferences for potential services by tackling the value generation process from the consumer perspective (Priem et al., 2012). In particular, the main theoretical foundation of our study lies on the elements of novelty, complementarity, efficiency, and lock-in, as defined by Amit and Zott (2001) to the extent that they explain the preferences for the provision of energy services. In the context of energy services, these can be described as:

- **Novelty**: innovation can take the form of innovative products, services or transactions, such as e.g. the possibility to rent the roof to the utility company (Drury et al., 2012), to sign a lease contract for the purchase of a PV system (Rai and

Sigrin, 2013), or to engage in demand management activities. Besides cost-benefit considerations, novelty generates value by capturing hidden consumer needs (e.g. enabling individuals to take decisions that comply with their environmental beliefs), and opening new markets. we can derive that:

Hypothesis 1 – The "rent-a-roof" solution (utility ownership of the PV system) is preferred to "plug-and-play" (household ownership).

- **Complementarities**: a solution that enables the adoption of a battery storage connected to a PV system might generate extra value for both prosumers and non-prosumers if the technology is perceived to optimize self-consumption and distribution of the electricity generated in-house; therefore, we derive

  Hypothesis 2 – A solution with battery storage is always preferred to a PV system without storage unit.

- **Efficiency**: a reduction in search, information, and planning costs (transaction costs) might result from the introduction of innovative services. This could be for instance the case of a PV system purchased through an installer who offers the "all-inclusive" formula, or of a system operated by the energy utility. Additionally, being control over the PV system an activity that requires technical knowledge on the side of its owner, external control over the system might become a valuable and more efficient way of managing the PV system for particularly risk-averse consumers (Richter, 2012). This is particularly true in the presence of information asymmetry and uncertainty about the future stream of revenue from the investment in PV system on the household side. Control over the PV system is indeed one of the key elements in the customer-utility relationship as it grants bargaining power to the households (Geelen et al., 2013).[2] We conclude that:

  Hypothesis 3 – Purchase and installation through a professional installer (the "all-inclusive" formula) is the preferred sales channel, and that:

  Hypothesis 4 – External control and maintenance of the PV system are preferred

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[2] Control was recently investigated by Broberg and Persson (2016), with a particular reference to electricity demand management measures and discomfort.

to household control.

- **Lock-in**: by building trust, efficiency and novelty play a positive role in retaining satisfied customers. In the energy market, this translates into lock-in with an energy retailer and results in contracts of longer lengths that minimize the uncertainty and risk of switching to another electricity provider (Defeuilley, 2009). We hypothesize that:

  Hypothesis 5 – Contracts of longer length for the supply of electricity from the grid are preferred to shorter ones.

Based on the prospect theory (Kahneman and Tversky, 1979) and the idea that costs and not benefits represent the main decisional driver for this type of investment, we additionally hypothesize that:

> **Hypothesis 6**: Respondents perceive benefits and costs of self-producing electricity differently meaning that respondents value investment costs of the system more than earnings from selling PV electricity and savings on the electricity bill.

The value generated in the transaction is captured by the multivariate utility function whose specification is discussed in Section 3.1.1 further below.

2.2 The data

Our data sample consists of 835 Italian owner-occupiers randomly selected across two groups of the population, viz. those who had already adopted a PV system at the time of the survey (423 respondents) and those considered as knowledgeable non-adopters, i.e. respondents with an interest and basic knowledge of PV systems (412 respondents). We screened out respondents that were not involved in the decision to invest; however, we cannot claim that the sub-group of knowledgeable non-adopters only comprises individuals involved in the household decisional processes. The survey was conducted in October 2014 by the professional fieldwork agency Norstat Deutschland GmbH – the owner of the market research panel "Opinion People" using the Computer Assisted Web Interview (CAWI) technique. Due to the high drop-out rates, the recruiting process was conducted in two stages: (i) a pre-selection phase in which only home-owners and owners of PV systems – distributed at the national level on a representative base according to age, gender, and region – were sent an invitation; (ii) a second phase in which all the remaining members of the panel were invited, again respecting the criteria of national representativeness. Because of the on-line recruitment strategy we cannot be sure that the sample is perfectly representative for the Italian population. In particular, it is likely that the elderly are systematically under-represented.[3] Table 1 summarizes the main socio-demographic characteristics of the sampled owner-occupiers by PV ownership (N=835).

Table 1: Characteristics of the sample (N=835)

	PV owners (%)	**PV non-owners (%)**
Gender		
Male	63.1	58.5
Female	36.9	41.5
Age group (Years)		
18-34	26.2	30.8
35-54	56.5	47.8
55-74	16.5	20.9
≥75	0.5	0.5
Net household income (€)		
<24,000	14.9	26.2
24,000-35,999	26.0	27.2
36,000-47,999	20.3	16.5
48,000-59,999	13.7	9.7
60,000-71,999	6.6	3.9
72,000-83,999	5.0	3.4
84,000-99,999	1.7	1.5
≥ 100,000	3.3	1.5
I prefer not to reply	8.5	10.2
Geographical location		
North	39.7	42.2
Center	22.0	17.2
South	23.2	25.7
Islands	15.1	14.8

Additional descriptive statistics revealed that 92% of the PV owners had the system connected to the grid. Among them, about 64% and 20% signed a net metering contract and a purchase-and-resale agreement, respectively. This means that the majority of respondents owning a PV system was still buying electricity from the grid at the time of the survey.

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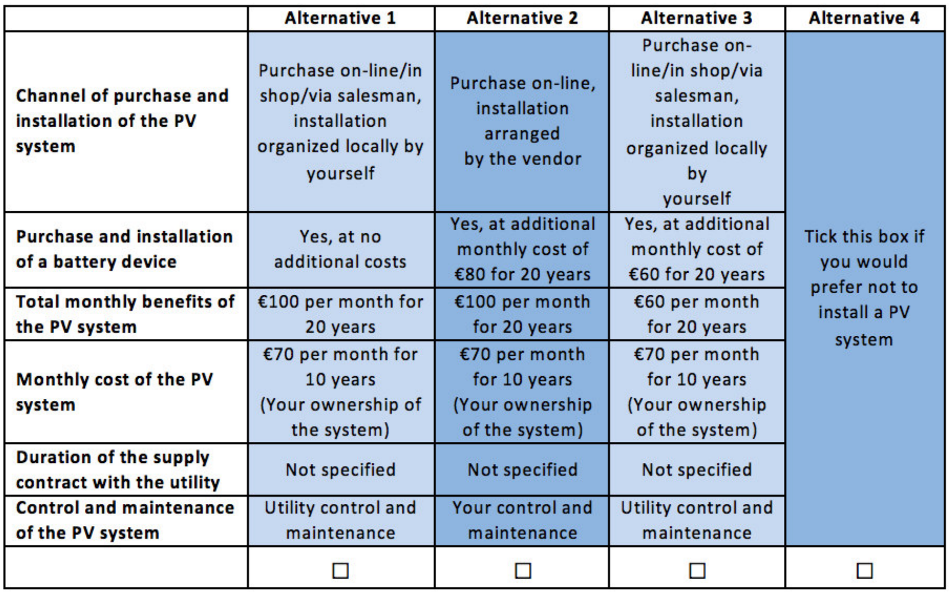
[3] The findings of a study conducted by Willis et al. (2011) reveal that people aged ≥ 65 are less likely to invest in micro-generation technologies (MGT) anyway. On MGT preferences see also Oberst and Madlener (2014)

2.3 The design of the Discrete Choice Experiment

DCE is a survey methodology consisting of cards containing a set of alternatives among which respondents have to choose. Each alternative differs for the values randomly taken on by adequately-chosen attributes of products or services. In taking their decision, rational respondents trade off the attributes based on the importance they cover in their decisional process. Thus, by keeping track of the decision-making patterns across choice cards, the researcher can elicit customer preferences. We asked both PV adopters and knowledgeable non-adopters to imagine a situation in which they had to choose whether or not to invest in a PV system with predetermined technical characteristics. Respondents were presented with 15 randomized choice cards and two holdouts[4], each containing three unlabelled alternatives and a “none-of-the-previous” option, similar to that shown in Figure 1.



	Alternative 1	**Alternative 2**	**Alternative 3**	**Alternative 4**
Channel of purchase and installation of the PV system	Purchase on-line/in shop/via salesman, installation organized locally by yourself	Purchase on-line, installation arranged by the vendor	Purchase on-line/in shop/via salesman, installation organized locally by yourself	Tick this box if you would prefer not to install a PV system
Purchase and installation of a battery device	Yes, at no additional costs	Yes, at additional monthly cost of €80 for 20 years	Yes, at additional monthly cost of €60 for 20 years	
Total monthly benefits of the PV system	€100 per month for 20 years	€100 per month for 20 years	€60 per month for 20 years	
Monthly cost of the PV system	€70 per month for 10 years (Your ownership of the system)	€70 per month for 10 years (Your ownership of the system)	€70 per month for 10 years (Your ownership of the system)	
Duration of the supply contract with the utility	Not specified	Not specified	Not specified	
Control and maintenance of the PV system	Utility control and maintenance	Your control and maintenance	Utility control and maintenance	
	☐	☐	☐	☐

Figure 1: Example of a choice card (translated from Italian into English)

Several sources contributed to inform attributes and their levels, i.e. a pilot survey conducted in 2013 among Italian PV system owners, technical as well as research reports, existing products and ads next to utility websites and the legislative framework. Attribute selection and specification was also guided by our findings from previous research suggest-

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[4] Holdouts are choice cards with a fixed combination of attribute levels across alternatives. Their use can serve several purposes; here two identical holdouts have been included to check the reliability of respondents and the predictive ability of the model.

ing that individuals do not have preferences for the technical characteristics of the PV system *per se* but rather for the services it provides. We therefore set the size of the PV modules and battery storage fixed to 3 kWp and 9.60 kWh respectively, which maximizes the possible level of electricity self-consumption of an average Italian household (ANIE, 2013).[5]

With the purpose to make the investment decisions more realistic, we specified the prohibitions between attribute levels A1.1 and A3.1; A1.1 and A5.1; A3.1 and A5.2; A3.1 and A5.3; A5.4 and A2.3. This implies that those combinations of attribute levels cannot be shown together. Attributes and their levels are summarized in Table 2.[6]

The DCE was designed following the Complete Enumeration randomization technique offered by Sawtooth Software®. A D-efficiency test with standard errors reported from the logit run proved this design-generation method to be more efficient than the shortcut, random, and balanced overlap methods, given the number of respondents, attributes, alternatives, and prohibitions present in the design. Moreover, the design is fractional factorial and full profile.

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[5] Details on the computation of the battery storage size to optimize self consumption are available from the authors upon request.

[6] Notice that A1 and A5 are a combination of two attributes. Concerning A1, the literature on PV business models confirms that control and maintenance can be taken into account jointly; regarding A5, the decision to combine preferences for the technology itself with the cost of installing it responds to the need to preserve orthogonality of the design.

Table 2: Attributes and their levels

Attribute	**Level**
A1. Control and maintenance of the PV system (CONTROL)	1.1 Your control and maintenance 1.2 Utility control and maintenance
A2. Total monthly benefits of the PV system (BENEFITS)	2.1 €60 per month for 20 years 2.2 €80 per month for 20 years 2.3 €100 per month for 20 years
A3. Monthly cost of the PV system (COSTS)	3.1 €0 (No ownership of the system) 3.2 €50 per month for 10 years (Your ownership of the system) 3.3 €70 per month for 10 years (Your ownership of the system)
A4. Length of the supply contract with the utility (CONTRACT)	4.1 Not specified 4.2 1 year 4.3 5 years 4.4 10 years
A5. Purchase and installation of a battery storage device (STORAGE)	5.1 Yes, at no additional costs 5.2 Yes, at additional monthly costs of €60 for 20 years 5.3 Yes, at additional monthly costs of €80 for 20 years 5.4 No
A6. Channel of purchase and installation of the PV system (SALES)	6.1 Purchase via installer, "all-inclusive" formula 6.2 Purchase on-line, installation arranged by the vendor 6.3 Purchase in a shop, installation arranged by the vendor 6.4 Purchase from a salesman, installation arranged by the vendor 6.5 Purchase on-line/in shop/via salesman, installation organized locally by yourself

3 Data analysis

3.1 The econometric model

3.1.1 The framework

In a DCE with n respondents involved, the choice of an alternative (or product) k for each subject i across m_i choice tasks results from the combination of a systematic component – the explained part of individual preferences – and an unobserved (random) one – the unexplained part of individual preferences. The subject-level utility Y_{ijk} can be written as:

$$Y_{ijk} = \bar{Y}(x_{ijk}, \beta) + \varepsilon_{ijk}, \tag{1}$$

where β represents the vector of model parameters, the observable component $\bar{Y}$ is a function of the attributes contained in the vector x – here composed of CONTROL, BENEFITS, COSTS, CONTRACT, STORAGE, and SALES – while the unobserved component is stochastic. Under the assumption of a linear relationship between attributes and utility, for i=1, ... , n and j=1, ... , m_i, the individual utility can be directly written as:

$$Y_{ijk} = \beta_{0i} + x'_{ijk}\beta_i + \varepsilon_{ijk}, \tag{2}$$

with the preference for “none-of-the-previous” option being captured by the parameter β_{0i} entering the model as an alternative-specific constant. In each choice task j the alternative k picked by a respondent is assumed to maximize her utility meaning that $Y_{ijv} \geq Y_{ijk}$, where v is the maximal latent utility achievable (Hess and Daly, 2014). The application of Bayesian statistics to the estimation of models in the framework of the Random Utility Theory (McFadden, 1973) is not new (Allenby and Lenk, 1994, 1995). However, in the energy field the Bayesian approach is to date mainly confined to the investigation of preferences for electric vehicles (e.g. Train and Sonnier, 2005; Daziano, 2013).

Our model uses the choice data to estimate both individual parameters (lower-level model) as well as the population parameters (upper-level model). Assumptions on the prior distribution of the population parameters are made by setting hyperparameters representing the mean and standard deviation of the population parameters, which gives rise to a hierarchical structure of the model. Finally, the random component of the utility – assumed to have an extreme value distribution – is responsible for producing logit choice probabilities. The power of Bayesian inference in capturing consumer heterogeneity with respect to other models (e.g. the commonly used mixed logit model) is twofold; (i) it borrows information from the population distribution of the parameter to efficiently estimate individual-level parameters; (ii) it allows the posterior distribution to take on a non-normal shape when diffuse priors are specified, as stressed in several studies (e.g. Allenby et al., 1998; Fiebig et al., 2010). Additionally, the usage of Bayesian methods proves to be especially useful in empirical applications where the classical maximum simulated likelihood estimator fails to converge due to the high number of parameters (Allison et al., 2004). For these reasons we chose to conduct Bayesian inference here.

3.1.2 Analysis of choice-based conjoint data with Hierarchical Bayes models

We estimated the parameters following the Hierarchical Bayes Multinomial Logit (HB-MNL) model with random effects. Following Hess and Daly (2014), the choice probabilities are:

$$P_{ij}(y = k|\beta_{0i}, \beta_i) = \frac{exp(\beta_{0i} + x'_{ijk}\beta_i)}{\sum\limits_{v=1}^{K} exp(\beta_{0i} + x'_{ijk}\beta_i)}, \tag{3}$$

where x' is a vector of dimension equal to the number of levels containing the values that attributes take on in each alternative of the choice task. The joint probability distribution of the data and all unknown quantities (full-probability model) can be written as:

$$\left[\prod_{i=1}^{n}\prod_{j=1}^{m_i}\prod_{k=1}^{K} P_{ij}(k \mid \beta_{0i}, \beta_i)^{\chi(Y_{ij}=k)}\right]\left[\prod_{i=1}^{n} h(\beta_{0i}, \beta_i \mid \theta, \Lambda)\right] g(\theta)g(\Lambda), \tag{4}$$

where the first bracket contains the MNL likelihood function in which the choice data enter, the second the heterogeneity distribution of the parameters conditional on θ and Λ – respectively the mean and covariance matrix of the distribution of the random parameters, priors of β_i, and β_{0i} – and $g(\cdot)$ are the prior distributions of the fixed coefficients, or hyperpriors. It follows that the log marginal distribution of the individual-level parameter β_i is:

$$LogL(\beta_i) = \sum_{j=1}^{m_i}\sum_{k=1}^{K} \chi(U_{ij} = k) ln\left[P_{ij}(k \mid \beta_{0i}, \beta_i)\right] + ln\left[h(\beta_i, \beta_{0i} \mid \theta, \Lambda)\right]. \tag{5}$$

Given the assumption of normality of the individual parameters β_{0i} and $\beta_i \sim N(\theta, \Lambda)$, the joint probability distribution takes on the form of a multivariate normal distribution. Because the hyperparameters θ and Λ are unknown, they have to be simultaneously estimated together with the individual parameters in a process that requires assumptions about the prior distribution (mean and covariance matrix, or hyperpriors) of these hyperparameters (hierarchical priors). Following the Full Bayes approach, the prior distributions are:

$$\theta \sim N(q_n, Q_n), \Lambda \sim IW_p(d_0, D_0), \tag{6}$$

where p indicates the dimension of the covariance matrix (i.e. 22 in our models), d_0 are the prior degrees of freedom, and D_0 is the scale matrix so that the prior mean of Λ is $D_0^{-1}/(d_0 - p - 1)$. Following Orme (2009), Dumont (2014), and Hess and Daly (2014), we set $q_n = 0$ and $Q_n = diag_p = 100$. Moreover, we specified the prior variance and degrees of freedom related to the Inverse Wishart distribution as $D_0 = diag_p(2)$ and $d_0 = 5$, respectively, while we set the covariance to zero.[7] By choosing these hyperparameters we ensured that the priors are diffuse, which should reduce the negative effect of prior misspecification on the parameter estimates. It is important to notice that setting prior covariance to zero does not impose a lack of correlation on the part-worth estimates; in fact, the HB model updates the prior attribute correlation structure allowing for correlation to take place whenever present.

The choice data enters the models through the likelihood function and updates the prior belief about the parameters by applying Bayes' rule; in fact, given the *a-priori* probability distribution of a vector of unobservables $p(X)$ and a likelihood function expressing the distribution of the observables y conditional on the unknown and unobservables X, the unnormalized joint posterior distribution $p(X|y)$ is proportional to the likelihood function and the priors. In mathematical form: $p(X|y) \propto p(y|X) * p(X)$. In order to be sure that convergence was achieved, 40,000 iterations were used as "burn-in" and another 40,000 iterations were used to estimate the model. Convergence was assessed with the help of a graph illustrating the oscillations of parameter estimates across draws. The mean of θ is the average across the latest 40,000 draws, while its standard deviation Q_n represents the classical standard errors associated to the estimation of θ. The same applies to the estimated variance-covariance matrix Λ. Overall, the process is robust and not dependent on the priors, as shown by the similarity between the posterior estimates of θ and the individual βs; in fact, diffuse priors coupled with the presence of a large quantity of data makes the likelihood function dominate the prior distribution.

Drawing part-worth estimates from one continuous and normally distributed prior corresponds to estimating a generic HB model assuming that individuals belong to the same population. We later relax this assumption estimating the model at the subpopulation level. Following the mixture of normals approach (Rossi et al., 2005) we included covariates in the upper-level model, a procedure that shrinks the individual parameters

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[7] Prior covariance takes on negative values among levels of the same attribute, thus avoiding any impact that effect coding might have on the parameter estimates.

towards multiple means and is equivalent to using variables for *a-priori* segmenting the sample. The introduction of covariates affects the heterogeneity distribution through a multivariate regression specification (Rossi et al., 2005):

$$\beta_i = B' z_i + \varepsilon_i, \tag{7}$$

with $\varepsilon_i \sim N(\theta_{ind_i}, \Lambda_{ind_i})$ and $ind_i \sim Multinomial_L(pvec)$. Moreover, B is the matrix of the mean of the parameter distributions, z_i is a vector of covariates, L counts the number of multivariate normals, $pvec$ is a vector of mixture probabilities of length L, and ind_i is a latent variable indicating to which component the observation i belongs. For this reason, the mean and covariance at the population level are not represented anymore by a single vector θ and covariance matrix Λ, but they are drawn from a normal distribution with prior means $B' z_i$ instead (Orme and Howell, 2009). Following Johnson (2000), we opted for not imposing monotonicity constraints on the part-worth estimates.

3.2 Results

For estimation purposes we filtered respondents using a variable that combines three criteria, i.e. "straightlining", "time", and "reliability".[8] The final number of eligible respondents dropped to 812, providing us with a total of 12,180 observations for our estimations.

3.2.1 Part-worth utilities

We obtained part-worth utilities from the estimation of several model specifications differing in the number of parameters, sample size, and structure of the priors. All estimations were performed using Sawtooth Software®.

Starting from the simple model specification with only the attributes of the DCE (model 1 in Table 3), we then included several covariates in the upper-level of models 2-12 (i.e. PV ownership, net household income, geographic location of the dwelling, as

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[8] We defined as straightliners respondents that in the DCE consecutively provided the same answer to at least 14 out of 17 choice tasks, or that they gave at least 16 out of 17 identical responses; in fact, no specific patterns should be observed in the choice of alternatives across tasks, nor should a respondent have a strict preference for the "none" option. The variable "time" is computed from the the elapsed time and takes the value of "1" if respondents' answering time is above the 5th percentile of the distribution of the elapsed time represented by 285.85 seconds. The variable "consist" captures reliability of respondents across choice tasks and takes the value of unity if respondents chose the same alternative across the two identical holdout tasks. We filtered respondents out if they reported a value of "2" in two out of the three above-mentioned variables. Aware of the debate around "irrational" responses (Lancsar and Louviere, 2006), we were cautious regarding dropping observations.

well as age and gender of the respondents) in an attempt to avoid the negative effects of Bayesian shrinkage towards one single mean in the presence of sub-populations and explain heterogeneity.[9] In model 13, benefits and costs of a PV system have been interacted with each other while following the recommendation in Howell (2007) we also estimated the model on a sample split by PV ownership (see model 4 and 14-17 in Table 3) and using as covariates household net income, location of the dwelling, age and gender of the respondents. All model specifications reported in Table 3 account for the presence of the "None" option, estimate the same number of parameters, and are identical in terms of attribute part-worth (and effect) coding.

All models were compared on the basis of their Mean Absolute Error (MAE), a measure for the predictive ability of a model. The MAE was computed as the average of the difference between the predicted product shares – resulting from simulations based on part-worth estimates of alternatives showing the same features contained in the holdouts – and actual holdout shares across the eight alternatives of the two holdouts[10]. Simulations were conducted by adopting the Randomized First Choice (RFC) model (Orme and Baker, 2000). The smaller the MAE, the better the predictive ability of the model. Model comparison through MAE, however, is far from trivial in the case of a number of holdout tasks per respondent of less than five. This might justify the similarities across the MAEs for several models. Sentis and Geller (2010) also explain that the introduction of covariates might not improve the predictive validity of the model if an adequate number of observations was gathered for each respondent. Similarly, Kurz and Binner (2010, 2015) argue that the practice of using covariates does not match the gains promised by the theory. Based on considerations concerning MAE, McFadden's Pseudo R^2, and economic meaningfulness of the variables we eventually decided to focus on models 1–4. In particular, given the similarities between MAE and McFadden's Pseudo R^2 across models 1–4, we preferred model 1 to other specifications for reasons of parsimony and we

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[9] Additional models with household size as covariate were also estimated and are available from the authors upon request.

[10] Standard errors from the simulation are not reported here but are available upon request. For an application of holdouts to model comparison in the framework of Bayesian analysis see e.g. Yang and Allenby (2000) or Otter et al. (2004).

Table 3: MAEs for different model specifications

Model	Sample	Int.	Cov.	McFadden's Pseudo R^2	MAE
1	Pooled	No	No	0.5461	0.6375
2	Pooled	No	PV own.	0.5474	0.6400
3	Pooled	No	Age	0.5467	0.6200
4	PV own.	No	No	0.5003	1.0538
	Non-PV own.			0.6269	0.8350
5	Pooled	No	PV own., Income, Gender, Zone, Age	0.5516	0.6725
6	Pooled	No	PV own., Income	0.5495	0.6475
7	Pooled	No	PV own., Zone	0.5485	0.6725
8	Pooled	No	PV own., Gender	0.5471	0.6500
9	Pooled	No	PV own., Age	0.5473	0.6425
10	Pooled	No	Income	0.5492	0.6375
11	Pooled	No	Zone	0.5476	0.6325
12	Pooled	No	Gender	0.5475	0.6275
13	Pooled	A2×A3	No	0.5822	0.7175
14	PV own.	No	Income	0.5042	1.0600
	Non-PV own.			0.6332	0.9450
15	PV own.	No	Zone	0.5016	1.0560
	Non-PV own.			0.6298	0.8150
16	PV own.	No	Age	0.5001	1.0580
	Non-PV own.			0.6287	0.9025
17	PV own.	No	Gender	0.5007	1.0538
	Non-PV own.			0.6287	0.9375

performed the majority of the analysis based on utility results from this model only.

Bayesian inference is about the posterior distribution of the population parameters rather than the distribution of individual-level coefficients. Table 4 presents posterior average estimates of θ for models 1-4. In the presence of covariates (i.e. models 2-3), the intercept represents the mean population part-worth estimates when the dummy-coded covariate (e.g. PV ownership) takes the value of 0 in the design matrix, while the second column of models 2-4 represents the average difference in the population mean expected to take place when respondents take on the characteristic described by the covariate. All attributes in Table 4 show the expected sign. With some exceptions from model 3, signs are consistent across model specifications. For each model, we also reported the McFadden's Pseudo R^2. From model 1 it can be seen that utility ownership of the PV system (COSTS_1) is preferred to household installation and operation of the system. This finding confirms hypothesis 1 that the "rent-a-roof" solution – whether with or without battery storage – can find fertile ground in Italy. Similarly, externalizing control and maintenance (CONTROL_2)) is preferred to household control, confirming hypothesis 4 as well. While benefits are mostly not credible, the only exception being represented by model 4, costs are highly credible and with the expected sign across all model specifications, which suggests that hypothesis 6 is confirmed.

When it comes to the usage of a battery storage, we find that respondents generally understand the benefits deriving from energy storage devices (sign of STORAGE_1 while STORAGE_4 is not credible) in accordance with the complementarity narrative described in paragraph 2.1. For this reason, we can also confirm hypothesis 2. However, respondents value the device less if they have to pay for it (sign of STORAGE_2 and STORAGE_3 in comparison to sign of STORAGE_1). This finding seems to confirm once again the dominance of the rent-a-roof solution over the traditional plug-and-play model. Hypothesis 5 is confirmed by the sign of the CONTRACT levels, with unspecified lengths generating less value than contracts of longer durations. Moreover, a high and credible disutility is associated to sales channels leaving over to the household the burden of finding an installer. However, we reject hypothesis 3 since SALES_1 is not credible. Finally, the negative "None" constant indicates that a PV system would generally bring extra utility left unexplained by the attributes.

The variance-covariance matrix Λ of the posterior means of the part-worth estimates from model 1 (Table 5, standard errors available upon request) helps understanding the extent to which heterogeneity was captured by the parameters in the model. The high diagonal elements – here all different from 0 at the 99% level of credibility – suggest the presence of heterogeneity in preferences for the attributes of the DCE. The off-diagonal elements in the upper part of the matrix inform about similarities in the evaluation of different attributes and, therefore, heuristic behaviors. Pearson's correlation coefficients were computed using the formula $\rho = \frac{COV(X,Y)}{\sigma_x \sigma_y}$ for those attributes involved in the spec-

Table 4: Point estimates of θ (Models 1–4)

Levels	Model 1	Model 2		Model 3		Model 4	
		Intercept	PV	Intercept	Age	PV	Non-PV
CONTROL_1	-0.172***	-0.240***	0.135**	-0.145*	-0.001	-0.097**	-0.322***
	(0.039)	(0.017)	(0.059)	(0.053)	(0.001)	(0.024)	(0.102)
CONTROL_2	0.172***	0.240***	-0.135**	0.145*	0.001	0.097**	0.322***
	(0.039)	(0.017)	(0.059)	(0.053)	(0.001)	(0.024)	(0.102)
BENEFITS_1	-0.024	0.068	-0.177**	-0.049	0.001	-0.096**	0.043
	(0.041)	(0.037)	(0.074)	(0.090)	(0.003)	(0.031)	(0.056)
BENEFITS_2	-0.031	-0.065	0.073	0.007	-0.001	-0.008	-0.089*
	(0.035)	(0.036)	(0.078)	(0.011)	(0.001)	(0.015)	(0.011)
BENEFITS_3	0.054	-0.003	0.105	0.042	0.000	0.103**	0.046
	(0.045)	(0.001)	(0.003)	(0.079)	(0.001)	(0.015)	(0.046)
COSTS_1	0.550***	0.833***	-0.546***	0.466**	0.002	0.305***	0.986***
	(0.068)	(0.088)	(0.056)	(0.109)	(0.003)	(0.057)	(0.069)
COSTS_2	-0.173***	-0.289***	0.215***	-0.095	-0.002	-0.066	-0.376***
	(0.044)	(0.009)	(0.035)	(0.037)	(0.001)	(0.057)	(0.072)
COSTS_3	-0.376***	-0.545***	0.331***	-0.371***	0.000	-0.239***	-0.610***
	(0.046)	(0.079)	(0.090)	(0.072)	(0.002)	(0.000)	(0.002)
CONTRACT_1	-0.080**	-0.038	-0.072	0.083	-0.004	-0.116**	-0.057
	(0.042)	(0.045)	(0.023)	(0.138)	(0.003)	(0.021)	(0.089)
CONTRACT_2	-0.121***	-0.121**	-0.003	-0.011	-0.003	-0.129**	-0.146**
	(0.043)	(0.044)	(0.016)	(0.061)	(0.003)	(0.055)	(0.024)
CONTRACT_3	0.100***	0.122**	-0.048	0.171	-0.002	0.071	0.160**
	(0.041)	(0.070)	(0.058)	(0.137)	(0.003)	(0.009)	(0.063)
CONTRACT_4	0.101**	0.036	0.123*	-0.243*	0.008**	0.175***	0.043
	(0.046)	(0.068)	(0.020)	(0.061)	(0.003)	(0.043)	(0.049)
STORAGE_1	0.726***	0.908***	-0.366***	-0.120	0.020***	0.559***	1.059***
	(0.060)	(0.023)	(0.063)	(0.050)	(0.002)	(0.0350)	(0.116)
STORAGE_2	-0.337***	-0.382***	0.121	0.167	-0.012***	-0.276***	-0.456***
	(0.057)	(0.013)	(0.017)	(0.167)	(0.004)	(0.003)	(0.040)
STORAGE_3	-0.412***	-0.491***	0.154*	0.026	-0.010***	-0.345***	-0.594***
	(0.059)	(0.052)	(0.142)	(0.103)	(0.001)	(0.063)	(0.066)
STORAGE_4	0.024	-0.035	0.091	-0.074	0.002	0.063	-0.009
	(0.054)	(0.041)	(0.096)	(0.014)	(0.001)	(0.025)	(0.090)
SALES_1	0.051	0.103*	-0.110	0.018	0.001	0.016	0.072
	(0.048)	(0.040)	(0.060)	(0.092)	(0.002)	(0.052)	(0.008)
SALES_2	-0.000	-0.004	-0.003	0.029	-0.001	-0.016	0.025
	(0.0490)	(0.078)	(0.010)	(0.005)	(0.001)	(0.004)	(0.017)
SALES_3	0.048	0.091*	-0.061	-0.002	0.002	0.022	0.111*
	(0.043)	(0.014)	(0.022)	(0.075)	(0.001)	(0.042)	(0.072)
SALES_4	0.052*	0.040	0.021	-0.190*	0.006**	0.045	0.098
	(0.040)	(0.037)	(0.042)	(0.112)	(0.001)	(0.060)	(0.127)
SALES_5	-0.151***	-0.230***	0.153**	0.145	-0.007**	-0.067	-0.306***
	(0.049)	(0.013)	(0.114)	(0.060)	(0.002)	(0.053)	(0.047)
None	-3.501***	-2.171***	-2.895***	-5.160***	0.036**	-4.271***	-2.184***
	(0.304)	(0.113)	(0.202)	(0.070)	(0.002)	(0.363)	(0.312)
McFadden's Pseudo R^2	0.5461	0.5474		0.5467		0.5003	0.6269

Level of credibility: *** = 99% ; ** = 95%; * = 90%.
Standard errors in brackets

ification of prohibitions and therefore more prone to show correlation (see the lower part of the Λ matrix). While some correlation between levels is expected to be present (e.g. between the lowest level of benefits and costs) and naturally occurs across levels of the same attribute, there should be independence across levels of different attributes if these were appropriately chosen and the design was optimal. The model indeed accommodates the presence of prohibitions in the design well, resulting in no correlation of the attributes involved. In addition to that, the correlation coefficients between the "None" and the attribute-level parameters are above 0.3 only in few cases, which signals the presence of some heuristics in the decisional process. For instance, individuals having a strict preference for specified contract lengths (negative coefficient of A4.1) also show strong preferences for choosing one of the three alternatives (negative coefficient of "None" but positive correlation coefficient equal to .262). Similarly, individuals having a strong preference for a battery storage facility at no extra cost (positive coefficient of A5.1) also demonstrate a strong preference for adopting a PV system (negative coefficient of "None" and positive correlation equal to .276). Finally, those highly disliking paying an additional amount of €80 for having the storage installed, signal their preference for the "None" alternative ($\rho = -.304$).

Table 5: Posterior variance-covariance matrix Λ and Pearson's correlation coefficients across the parameters (from Model 1)

	A1.1	A1.2	A2.1	A2.2	A2.3	A3.1	A3.2	A3.3	A4.1	A4.2	A4.3	A4.4	A5.1	A5.2	A5.3	A5.4	A6.1	A6.2	A6.3	A6.4	A6.5	None
A1.1	**.323**	-.323	.074	-.000	-.074	.047	-.048	.002	-.046	.001	.015	.031	-.042	.023	.076	-.057	-.009	-.011	.005	.006	.008	-.565
A1.2		**.323**	-.074	.000	.074	-.047	.048	-.002	.046	-.000	-.015	-.031	.042	-.023	-.076	.057	.009	.011	-.005	-.006	-.008	.565
A2.1			**.628**	-.139	-.489	.063	-.039	-.024	.061	.042	.004	.024	-.086	.068	.025	-.006	-.035	.022	.014	-.013	.012	-.283
A2.2				**.333**	-.193	.057	.041	.016	.044	-.009	-.025	-.011	.014	.019	-.010	-.023	.019	.013	.022	.011	.027	.344
A2.3					**.682**	-.005	-.002	.008	.017	.034	.029	-.013	.073	-.086	-.016	.029	.016	-.008	.008	.024	-.040	-.061
A3.1	.060	-.060	.521	.047	.004	**1.924**	-.896	-1.028	.019	-.009	.013	-.024	.327	-.159	-.192	.024	.002	-.019	.024	-.045	.038	1.558
A3.2	-.104	.104	-.609	.188	.004		**.654**	.242	-.003	-.006	-.016	.025	-.116	.076	.056	-.016	-.034	-.003	.010	.025	.002	-.647
A3.3	.004	-.004	-.487	.061	.015			**.785**	-.017	.015	.003	-.002	-.211	.083	.136	-.008	.033	.022	-.034	.020	-.040	-.912
A4.1									**.587**	-.022	-.245	-.320	.054	-.035	-.086	.067	.038	.011	.039	.029	.041	1.082
A4.2										**.554**	-.164	-.368	-.022	.014	-.011	.019	-.031	-.005	-.026	.008	.054	.134
A4.3											**.478**	-.069	.047	.002	.003	-.053	.003	.019	.019	-.010	-.031	-.491
A4.4												**.758**	-.079	.019	.094	-.033	-.010	-.002	.045	.031	-.064	-.725
A5.1	-.064	.064	-.095	.021	.077	.206	-.125	-.208					**1.313**	-.468	-.627	-.218	.061	.017	.030	-.067	-.041	1.707
A5.2	.056	-.056	.118	.045	-.144	-.158	.130	.129						**.526**	.149	-.207	-.024	.012	-.009	.004	.017	-.651
A5.3	.160	-.160	.038	-.021	-.023	-.165	.083	.183							**.702**	-.224	-.015	-.010	.007	.021	-.003	-1.375
A5.4	-.124	.124	-.009	-.049	.044	.021	-.025	-.011								**.649**	-.022	-.019	-.028	.042	.027	.318
A6.1																	**.560**	-.138	-.112	-.093	.216	.150
A6.2																		**.472**	-.136	-.135	-.063	-.196
A6.3																			**.465**	-.081	-.136	-.224
A6.4																				**.435**	.126	.044
A6.5																					**.541**	.225
None	-.184	.184	-.066	.111	-.014	.208	-.148	-.191	.262	.033	-.132	-.154	.276	-.166	-.304	.073	.037	-.053	-.061	.012	.057	**29.068**

Particularly big in magnitude are also the ρs between lower benefits (A2.1) and the costs (A3). More in particular, the higher the aversion for lower benefits (negative coefficient of A2.2), the more solutions with no initial investment costs are appreciated (positive sign of A3.1 and $\rho = 0.521$ and, specularly, the more solutions with high investment costs are disliked (negative signs of A3.2 and A3.3 with negative sign of ρs. Although benefits matter less than costs, these results signify that a lower level of benefits does play a role in determining one's willingness to invest on the PV system. The correlation coefficients between benefits and storage are, however, below 0.2 as well as those between cost of the PV system and storage, with the only exception of $\rho = 0.206$ between A3.1 and A5.1 to indicate a positive correlation between no ownership of the PV system and of the battery storage.

We also addressed the presence of taste heterogeneity across the two subgroups of PV adopters and knowledgeable non-adopters. To this end, we conducted the multivariate analysis of variance (MANOVA) on individual utilities from model 1 (rescaled using the zero-centered differences method) by setting α=0.05.[11] Results from the MANOVA analysis based on Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root Tests (not reported here) confirm that the estimates statistically differ across the two groups of PV adopters and non-adopters. However, only after normalizing the individual-level utilities of model 1 it becomes possible to compare results across the two sub-groups. By looking at Tables 6 and 7 we observe that utility ownership of the PV system as well as its control and maintenance are indeed valued more by knowledgeable non-adopters than adopters. Those who already installed a PV found paying for the adoption of a battery storage (STORAGE_2 and STORAGE_3) more valuable than knowledgeable non-adopters. PV owners also differ in terms of their preferences for sales channels, the option to purchase from a salesman (SALES_4) being their most preferred one against the "all-inclusive" model (SALES_1). Such differences across sub-groups, however, disappear in model 4. Overall, these findings suggest the presence of a higher aversion to risk on the side of the non-adopters than of the adopters.

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[11] We refer to Warne (2014) for a more accurate explanation of MANOVA analysis and its tests.

Assuming that the posterior distribution of the parameters is indeed normal, from the the cumulative area under the standard normal distribution (parameters from model 4), one can see that about 40% of the PV owners would be willing to give up control of the PV system whereas ca. 42% would prefer not to own one.[12] With a share of small-scale installations of about 90%, these figures suggest that ca. 1,500 MW of installed capacity would now belong to utilities rather than consumers if the rental roof option was available in the market, with positive effect on their stream of revenue (Gestore Servizi Energetici, 2015).

Table 6: Models 1 and 4 – Normalized and zero-centered utilities

	Model 1			**Model 4**	
Levels	**All resp.** ***N*=(812)**	**PV** ***N*=(403)**	**Non-PV** ***N*=(409)**	**PV** ***N*=(403)**	**Non-PV** ***N*=(409)**
CONTROL_1	-13.75	-10.05	-17.40	-7.35	-19.49
CONTROL_2	13.75	10.05	17.40	7.35	19.49
BENEFITS_1	-1.08	-4.60	2.39	-7.41	4.07
BENEFITS_2	-2.07	-1.00	-3.13	-0.12	-5.56
BENEFITS_3	3.15	5.60	0.73	7.53	1.49
COSTS_1	40.67	24.00	57.10	22.21	55.56
COSTS_2	-12.32	-5.52	-19.03	-4.50	-21.02
COSTS_3	-28.35	-18.48	-38.08	-17.72	-34.54
CONTRACT_1	-6.68	-10.19	-3.22	-9.51	-3.26
CONTRACT_2	-10.04	-11.09	-9.01	-10.49	-8.86
CONTRACT_3	8.34	8.72	7.97	5.69	10.40
CONTRACT_4	8.38	12.56	4.26	14.31	1.71
STORAGE_1	58.52	47.10	69.78	45.16	62.17
STORAGE_2	-27.69	-23.38	-31.52	-22.97	-26.65
STORAGE_3	-33.27	-26.26	-40.18	-27.97	-34.77
STORAGE_4	2.43	2.96	1.91	5.78	-0.74
SALES_1	4.17	1.93	6.39	0.65	5.08
SALES_2	0.11	0.83	-0.59	-0.79	1.50
SALES_3	3.59	3.07	4.10	1.68	6.13
SALES_4	5.12	6.06	4.19	4.37	6.54
SALES_5	-12.99	-11.88	-14.08	-5.91	-19.24
None	-328.00	-448.68	-209.08	-382.35	-139.76

Robustness checks were also performed. Firstly, we estimated model 1 on the full sample of N=835 respondents to confirm that results are not dependent on the filtering criteria adopted. Then, we included the monetary attribute COSTS as a linear coded variable instead of part-worth, thus obtaining a worse fit and MAE.

3.2.2 Relative attribute importance and sensitivity analysis

Table 8 ranks attributes according to their relative importance computed as the best minus the worst level for each attribute (taken as a percentage across attributes to sum up to 100); as such, the ranking is affected by the prohibition settings. The most important

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[12] Percentages given by 100 X $\Phi(-b_l/sd_l)$ as in Hole (2007).

Table 7: Models 2 and 3 – Normalized and zero-centered utilities

Levels	**Model 2** **All resp.** N**=(812)**	 **PV** N**=(403)**	 **Non-PV** N**=(409)**	**Model 3** **All resp.** N**=(812)**	 **PV** N**=(403)**	 **Non-PV** N**=(409)**
CONTROL_1	-13.72	-8.68	-18.69	-13.91	-10.16	-17.61
CONTROL_2	13.72	8.68	18.69	13.91	10.16	17.61
BENEFITS_1	-0.86	-8.83	7.00	-0.83	-4.23	2.52
BENEFITS_2	-1.98	1.01	-4.93	-2.35	-1.26	-3.43
BENEFITS_3	2.84	7.82	-2.07	3.18	5.49	0.90
COSTS_1	40.98	21.46	60.22	40.46	24.05	56.63
COSTS_2	-12.80	-5.23	-20.25	-12.94	-5.94	-19.85
COSTS_3	-28.19	-16.23	-39.97	-27.51	-18.11	-36.78
CONTRACT_1	-6.17	-9.67	-2.72	-6.13	-9.49	-2.82
CONTRACT_2	-9.94	-10.80	-9.09	-10.69	-11.56	-9.83
CONTRACT_3	8.06	6.54	9.55	8.30	8.51	8.09
CONTRACT_4	8.05	13.93	2.26	8.52	12.54	4.57
STORAGE_1	57.55	45.74	69.18	57.77	46.41	68.97
STORAGE_2	-25.89	-22.72	-29.02	-26.23	-22.61	-29.80
STORAGE_3	-33.09	-28.81	-37.31	-33.65	-26.46	-40.74
STORAGE_4	1.43	5.79	-2.86	2.12	2.66	1.58
SALES_1	3.87	-1.22	8.88	3.29	1.19	5.36
SALES_2	-0.42	-0.15	-0.69	-0.59	0.17	-1.34
SALES_3	4.61	2.26	6.93	5.24	4.30	6.18
SALES_4	5.00	6.20	3.83	4.91	5.89	3.95
SALES_5	-13.06	-7.09	-18.95	-12.86	-11.54	-14.15
None	-337.79	-495.36	-182.53	-335.08	-456.65	-215.30

attribute is the installation of a battery storage system, a result that should not come as a surprise if we consider that STORAGE combines preferences for the technology itself with the cost of installing it.

Table 8: Model 1 – Estimated average attribute importance (%) and ranking

Ranking	**Attribute**	**All respondents** **(**N**=812)**	**PV owners** **(**N**=403)**	**PV non-owners** **(**N**=409)**
1	STORAGE	23.74	22.27	25.19
2	COSTS	22.59	20.32	24.83
3	CONTRACT	16.64	18.07	15.22
4	BENEFITS	14.25	15.33	13.19
5	SALES	14.03	15.94	12.16
6	CONTROL	08.75	08.08	09.41
	Total	100.00	100.00	100.00

Although it is not possible to disentangle the impact of these two effects, results suggest that respondents are actually able to perceive the intrinsic value of this innovative technology and its benefits on the quality of electricity supply. However, we think that in this case costs are the major drivers of the high rank. In fact, the cost of the PV system attribute is ranked in position 2. Unexpectedly, CONTROL is the least important attribute, coming after BENEFITS and SALES. Attribute importances and rankings vary only slightly between the two sub-groups: knowledgeable non-adopters place relatively more importance on STORAGE and COSTS than adopters do, the latter valuing more

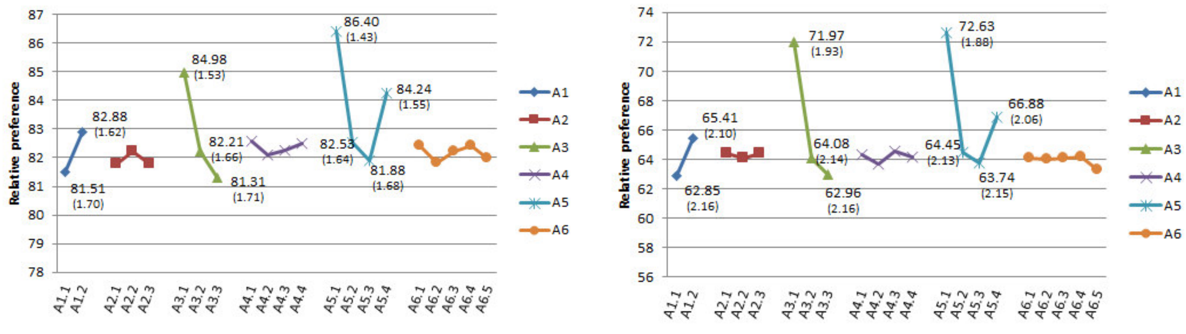
BENEFITS, CONTRACT, and especially SALES (ranking in 4th position among PV adopters). When comparing this ranking with the self-reported one[13] summarized in Table 9 we observe incongruences that deserve further attention.

Table 9: Attribute ranking and Friedman test statistics

		Percentiles		
	Mean rank	**25th**	**50th**	**75th**
CONTROL	3.50	2.00	3.00	5.00
BENEFITS	2.75	1.00	2.00	4.00
COSTS	2.52	1.00	2.00	4.00
CONTRACT	4.02	3.00	4.00	5.00
STORAGE	3.82	3.00	4.00	5.00
SALES	4.40	3.00	5.00	6.00
N=812		$\chi^2(5) = 624.292$		p=0.000

As affirmed by Louviere and Islam (2008), indirect measures of attribute importance (derived from DCEs) hold higher external validity because they account for attribute trade-offs.

Finally, we used part-worth estimates to compute the share of preferences (scaled 0-100) in the sensitivity analysis for both PV owners (Figure 2a) and non-owners (Figure 2b).



(a) PV owners

(b) PV non-owners

Figure 2: Sensitivity analysis

Sensitivity analyses illustrate how respondents' share of preferences for the above-mentioned market innovations varies when each attribute level is changed, while holding all other levels at the base case values (standard errors in brackets). It can be observed that for both sub-groups, utilities are particularly sensitive to attributes A1, A3, and

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[13] A lower mean rank corresponds to a higher ranking position. The Friedman test, commonly used to check for differences across groups when the dependent variable is ordinal, ensures that the difference in the average ranking of attribute importance across respondents is statistically significant (p=0.000).

A5. Preferences increase relatively when moving from household to utility control and maintenance of the PV system, and when shifting from higher to lower costs of PV systems. A relative increase in utility is also observable when shifting from solutions with costly batteries to alternatives where the battery comes at no cost or is not included in the system. Sensitivity analysis therefore clearly reveals the presence of differences in the perception of benefits and costs of the PV system (hypothesis 6) for both subgroups of respondents. Moreover, knowledgeable PV non-owners are more sensitive than PV owners to external control and maintenance of the PV system, a decrease in its monthly cost, and the presence of a battery storage, and are generally more prone not to adopt a PV system at all (overall smaller shares of preferences). Finally, knowledgeable non-adopters seem to be more sensitive to costs than adopters – a finding that hints at risk aversion.

4 Conclusions and policy recommendations

The diffusion of potentially disruptive energy technologies, such as residential PV systems with storage, can undermine the value generation mechanisms of traditional transactions in the energy market and thus change the structure of the entire energy supply system. Coping with these innovations makes it necessary to design long-term solutions which involve customer integration in the provision of electricity services. Such innovative models may foresee new ownership structures that allocate an active role to prosumers and consumers in the co-provision of energy services. It follows that (i) the utility of the future will be characterized by new consumer-producer interactions, and that (ii) it is of paramount importance to investigate customer preferences over the provision of innovative services before the energy utilities introduce new strategies.

Our case study of the Italian energy market has demonstrated that consumers would be eager to engage in partnerships with incumbent utilities for the distributed generation of renewable energy at the household level. We focused in particular on the element of novelty of market solutions – like the “rent-a-roof” concept (possibly including a battery storage) – based on external ownership, control, and maintenance of a system. Our results provide empirical evidence of the potential spread of the rent-a-roof concept in the Italian market. Roof rental can be particularly appealing to a segment of home-owners positively valuing PV systems (e.g. being "green") but highly risk-averse or lacking the financial means to do the investment (Scarpa and Willis, 2010). This seems to be also partially confirmed by the high searching costs, which make consumers particularly prone to choose "all inclusive"-type solutions, such as the roof rental one. Interestingly, consumers like the idea of longer contracts for the supply of electricity from the grid. In line with (Defeuilley, 2009), this might result from consumers being relatively satisfied with the service and wanting to minimize the uncertainty and risks from switching to an unknown electricity provider.

Our findings suggest further that PV owners probably would not have invested in the technology if renting a roof had already been an option at the time of their investment decision. Therefore, if implemented successfully, such a strategy would allow utilities to counteract or at least dampen the disruptive effects of PV systems with storage while enabling a green transition of the country, rather than resisting the growth in decentralized PV systems. With current and future PV investors less eager to give up control of their own system, the need for a market player able to divert potential prosumers away from investing in the PV technology is even stronger. Altogether, our results point to the "rent-a-roof" model as the sole valuable alternative to prosumption, especially in circumstances where FiTs are still in place. To conclude, besides benefiting the energy utility by generating a new stream of revenue, the roof rental option also generates value for the consumers through a set of advantages, such as access to reliable (and green energy), a more active role and more bargaining power in the relationship with the utility, as well as lower searching and investment costs. Therefore, the same distributed energy resources that carry disruptive effects and pose a threat to the current energy system, reveal themselves to actually be a blessing towards an improvement of the actual market conditions in many European countries still dominated by consumer inertia, when adequately exploited.

The contribution of our study to the existing literature is threefold: (i) we reconciled the value creation and prosumption theory to inform the attributes of our DCE; (ii) we followed the Bayesian approach to analyze consumer preferences; and (iii) based on quantitative methods, we argue and prove that incumbent utility companies can design coping strategies to effectively embrace the potentially disruptive character of PV systems with storage increasing the benefits for all actors of the energy systems.

Our study has also important, twofold policy implications: on the one hand, it confirms the importance of changing the regulatory framework to enable consumers to provide services such as ancillary services and arbitrage; on the other hand, it warns us of the negative effects of further incentives for the investment in PV systems on the utilities' market shares, with additional prosumers willing to join the market and gain independence from the grid.

It is worth noticing that in this work we generally referred to the company side of the transaction with consumers as the "utility company"; the disruptive effects of a broader diffusion of PV system with storage would affect generation as well as transmission and distribution. Which player in the energy market will provide the specific service to consumers is likely to depend on the regulatory framework. Regulations precluding electricity distribution companies the ownership of generation assets (and therefore also battery storage facilities) will of course impede the realization of this strategy on the distribution part of the supply chain.

A caveat of our analysis is rooted in the nature of the (DCE) methodology applied, which only allows the inclusion of a small number of treatments (i.e. our attributes). For this reason we decided to exclude some interesting new energy services – such as smart electricity tariff schemes and demand-side management options using smart appliances, feedback displays, and metering. Through the inclusion of different attributes, a plethora of further concepts (such as the community energy system) and services can be tested, which paves the way for abundant future research.

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References

Allenby, G.M. and P.J. Lenk, "Modeling household purchase behavior with logistic normal regression," *Journal of the American Statistical Association*, 1994, *89* (428), 1218–1231.

_ **and** _ , "Reassessing brand loyalty, price sensitivity, and merchandising effects on consumer brand choice," *Journal of Business & Economic Statistics*, 1995, *13* (3), 281–289.

_ **, N. Arora, and J.L. Ginter**, "On the heterogeneity of demand," *Journal of Marketing Research*, 1998, *35* (3), 384–389.

Allison, P., M. Altman, J. Gill, and M.P. McDonald, "Convergence Problems in Logistic Regression," in "Numerical Issues in Statistical Computing for the Social Scientist," John Wiley & Sons, Inc., 2004. Hoboken, NJ, USA.

Amador, F.J., R.M. González, and F.J. Ramos-Real, "Supplier choice and WTP for electricity attributes in an emerging market: The role of perceived past experience, environmental concern and energy saving behavior," *Energy Economics*, 2013, *40*, 953–966.

Amit, R. and C. Zott, "Value creation in E-business," *Strategic Management Journal*, 2001, *22* (6-7), 493–520.

ANIE, "Residential Electrical Storage Systems (RESS)," Technical Report, Federazione Nazionale delle Imprese Elettrotecniche ed Elettroniche, Milan, Italy September 2013.

Blansfield, J.C. and K.B. Jones, "Industry response to revenue erosion from Solar PVs," in F.P. Sioshansi, ed., *Distributed generation and its implications for the utility* *industry*, Boston: Academic Press, 2014.

Breyer, C. and A. Gerlach, "Global overview on grid-parity," *Progress in Photovoltaics: Research and Applications*, 2013, *21* (1), 121–136.

Broberg, T. and L. Persson, "Is our everyday comfort for sale? Preferences for demand management on the electricity market," *Energy Economics*, 2016, *54*, 24–32.

Carlsson, F. and P. Martinsson, "Does it matter when a power outage occurs? — A choice experiment study on the willingness to pay to avoid power outages," *Energy Economics*, 2008, *30* (3), 1232 – 1245.

Christensen, C., *The innovator's dilemma: when new technologies cause great firms to fail*, Harvard Business School Press, 1997.

Colmenar-Santos, A., S. Campíñez-Romero, C. Pérez-Molina, and M. Castro-Gil, "Profitability analysis of grid-connected photovoltaic facilities for household electricity self-sufficiency," *Energy Policy*, 2012, *51*, 749–764.

Daziano, R.A., "Conditional-logit Bayes estimators for consumer valuation of electric vehicle driving range," *Resource and Energy Economics*, 2013, *35* (3), 429–450.

Defeuilley, C., "Retail competition in electricity markets," *Energy Policy*, 2009, *37* (2), 377–386.

Drury, E., M. Miller, C.M. Macal, D.J. Graziano, D. Heimiller, J. Ozik, and T.D. Perry IV, "The transformation of southern California's residential photovoltaics market through third-party ownership," *Energy Policy*, 2012, *42*, 681–690.

Dumont, J., "How to use RSGHB. R package version 1.0.2.," Available at: `https://cran.r-project.org/web/packages/RSGHB/index.html` 2014. Last accessed: 07/08/2016.

Energy & Strategy Group, "Smart Grid Report. Sistemi di storage e auto elettrica," Technical Report, Energy & Strategy Group, Milan, Italy 2013.

Eurostat, "Electricity price statistics," Available at: `http://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_price_statistics` 2015. Last accessed: 12/08/2016.

Fiebig, D.G., M.P. Keane, J. Louviere, and N. Wasi, "The generalized multinomial logit model: Accounting for scale and coefficient heterogeneity," *Marketing Science*, 2010, *29* (3), 393–421.

Frantzis, L., S. Graham, R. Katofsky, and H. Sawyer, "Photovoltaics Business Models," Subcontract Report NREL/SR-581-42304, National Renewable Energy Laboratory February 2008.

Geelen, D., A. Reinders, and D. Keyson, "Empowering the end-user in smart grids: Recommendations for the design of products and services," *Energy Policy*, 2013, *61*, 151–161.

Gestore Servizi Energetici, "Rapporto statistico. Energia da fonti rinnovabili. Anno 2015.," 2015. Available at: www.gse.it, Last accessed: 19/09/2016.

Hess, S. and A. Daly, *Handbook of choice modelling*, Edward Elgar, Cheltenham, UK, 2014.

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

Hoppmann, J., J. Volland, T.S. Schmidt, and V.H. Hoffmann, "The economic viability of battery storage for residential solar photovoltaic systems – A review and a simulation model," *Renewable and Sustainable Energy Reviews*, 2014, *39*, 1101–1118.

Howell, J., "Respondent weighting in HB," in "Sawtooth Software Conference Proceedings" October 2007. Available at: http://www.sawtoothsoftware.com/support/technical-papers/conference-proceedings/proceedings2007.

Ida, T., K. Murakami, and M. Tanaka, "A stated preference analysis of smart meters, photovoltaic generation, and electric vehicles in Japan: Implications for penetration and GHG reduction," *Energy Research & Social Science*, 2014, *2*, 75–89.

Islam, T., "Household level innovation diffusion model of photo-voltaic (PV) solar cells from stated preference data," *Energy Policy*, 2014, *65*, 340–350.

_ **and N. Meade**, "The impact of attribute preferences on adoption timing: The case of photo-voltaic (PV) solar cells for household electricity generation," *Energy Policy*, 2013, *55*, 521–530.

Johnson, R.M., "Monotonicity constraints in choice-based conjoint with hierarchical Bayes," in "Sawtooth Software Research Paper Series" 2000.

Kahneman, D. and A. Tversky, "Prospect theory: An analysis of decision under risk," *Econometrica*, 1979, *47* (2), 263–292.

Kurz, P. and S. Binner, "Added Value through Covariates in HB Modeling?," in "Sawtooth Software Conference Proceedings" October 2010. Available at: http://www.sawtoothsoftware.com/support/technical-papers/conference-proceedings/proceedings2010.

_ and _, "Capturing Individual Level Behavior in DCM.," in "Sawtooth Software Conference Proceedings" March 2015. Available at: https://www.sawtoothsoftware.com/training/conferences/100-support/proceedings/1620-proceedings2015.

Lancsar, E. and J.J. Louviere, "Deleting 'irrational' responses from discrete choice experiments: a case of investigating or imposing preferences?," *Health Economics*, 2006, *15* (8), 797–811.

Louviere, J. J. and T. Islam, "A comparison of importance weights and willingness-to-pay measures derived from choice-based conjoint, constant sum scales and best–worst scaling," *Journal of Business Research*, 2008, *61* (9), 903–911.

McFadden, D., "Conditional logit analysis of qualitative choice behavior," in P. Zarembka, ed., *Frontiers in Econometrics*, Academic Press, 1973. New York.

Oberst, C. and R. Madlener, "Prosumer Preferences Regarding the Adoption of Micro-Generation Technologies: Empirical Evidence for German Homeowners," in "FCN Working Paper" number No. 22/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December 2014. Revised September 2015.

Orme, B., *CBC/HB v5. Software for hierarchical Bayes estimation for CBC Data* 2009.

_ and G.C. Baker, "Comparing hierarchical Bayes draws and randomized first choice for conjoint simulations," in "Sawtooth Software Research Paper Series" 2000. Available at: http://www.sawtoothsoftware.com/support/technical-papers#market-simulations.

_ **and J. Howell**, "Application of covariates within Sawtooth's Software CBC/HB program: Theory and practical example," in "Sawtooth Software Research Paper Series" 2009.

Otter, T., R. Tüchler, and S. Frühwirth-Schnatter, "Capturing consumer heterogeneity in metric conjoint analysis using Bayesian mixture models," *International Journal of Research in Marketing*, 2004, *21* (3), 285–297.

Palmer, J., G. Sorda, and R. Madlener, "Modeling the diffusion of residential photovoltaic systems in Italy: An agent-based simulation," *Technological Forecasting and Social Change*, 2015, *99*, 106–131.

Priem, R.L., S. Li, and J.C. Carr, "Insights and new directions from demand-side approaches to technology innovation, entrepreneurship, and strategic management research," *Journal of Management*, 2012, *38* (1), 346–374.

Rai, V. and B. Sigrin, "Diffusion of environmentally-friendly technologies: buy versus lease differences in residential PV markets," *Environmental Research Letters*, 2013, *8* (1), 1–8.

Richter, M., "Utilities' business models for renewable energy: A review," *Renewable and Sustainable Energy Reviews*, 2012, *16* (5), 2483–2493.

_ , "German utilities and distributed PV: How to overcome barriers to business model innovation," *Renewable Energy*, 2013, *55*, 456–466.

Rossi, P.E., G.M. Allenby, and R. McCulloch, *Bayesian Statistics and Marketing*, 1 ed., Wiley Series in Probability and Statistics, John Wiley & Sons, Chichester, England, 2005.

Sauter, R. and J. Watson, "Strategies for the deployment of micro-generation: Implications for social acceptance," *Energy Policy*, 2007, *35* (5), 2770–2779.

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

Schoettl, J.-M. and L. Lehmann-Ortega, "Photovoltaic business models: Threat or opportunity for utilities?," in R. Wüstenhagen and R. Wuebker, eds., *Handbook of research on energy entrepreneurship*, Edward Elgar, Cheltenham, UK, 2011, chapter 8.

Sentis, K. and V. Geller, "The impact of covariates on HB estimates," in "Sawtooth Software Conference Proceedings" October 2010. Available at: http://www.sawtoothsoftware.com/support/technical-papers/conference-proceedings/proceedings2010.

Shomali, A. and J. Pinkse, "The consequences of smart grids for the business model of electricity firms," *Journal of Cleaner Production*, 2016, *112, Part 5*, 3830–3841.

Sioshansi, F.P., "Decentralized energy: Is it as imminent or serious as claimed?," in F.P. Sioshansi, ed., *Distributed generation and its implications for the utility industry*, Boston: Academic Press, 2014.

Train, K. and G. Sonnier, "Mixed logit with bounded distributions of correlated partworths," in "Applications of Simulation Methods in Environmental and Resource Economics," Springer Verlag, Dordrecht, 2005.

Udwadia, F.E. and K.R. Kumar, "Impact of customer coconstruction in product/service markets," *Technological Forecasting and Social Change*, 1991, *40* (3), 261–272.

van Vliet, B., "Differentiation and ecological modernization in water and electricity provision and consumption," *Innovation: The European Journal of Social Science Research*, 2003, *16* (1), 29–49.

Vargo, S.L. and R.F. Lusch, "Evolving to a New Dominant Logic for Marketing," *Journal of Marketing*, 2004, *68* (1), 1–17.

Warne, R.T., "A primer on multivariate analysis of variance (MANOVA) for behavioral scientists.," *Practical Assessment, Research & Evaluation*, 2014, *19* (17), 1–10.

Watson, J., "Co-provision in sustainable energy systems: the case of micro-generation," *Energy Policy*, 2004, *32* (17), 1981–1990.

_ , R. Sauter, B. Bahaj, P.A. James, L. Myers, and R. Wing, "Unlocking the power house: Policy and system change for domestic micro-generation in the UK," October 2006.

Willis, K., R. Scarpa, R. Gilroy, and N. Hamza, "Renewable energy adoption in an ageing population: Heterogeneity in preferences for micro-generation technology adoption," *Energy Policy*, 2011, *39* (10), 6021–6029.

Wood, L. and R. Borlick, "Value of the grid to DG customers," *Institute for Electric Innovation Issue Brief*, 2013.

Yang, S. and G. Allenby, "A model for observation, structural, and household heterogeneity in panel data," *Marketing Letters*, 2000, *11* (2), 137–149.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

2012

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

2011

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

2010

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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 (revised September 2010).

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

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

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

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

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

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

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

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

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

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

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

2008

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

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

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

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

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.