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An Empirical Study of How Household Energy Consumption Is Affected by Co-Owning Different Technological Means to Produce Renewable Energy and the Production Purpose

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Abstract: The transition from fossil fuel-based to renewable energy sources is one of the main economic and social challenges of the early 21st century. Due to the volatile character of wind and solar power production, matching supply and demand is essential for this transition to be successful. In this context, the willingness of private consumers to use energy flexibly has gained growing attention. Research indicates that a viable driver to motivate consumers to be demand flexible is to make them (co-)owners of renewable energy production facilities. However, existing research has only analyzed this question from an aggregated perspective. This article analyses whether behavioral changes triggered by (co-)ownership in renewables differ according to the type of installation; be it solar, wind, or bioenergy. In addition, the prosumption options self-consumption/self-consumption and sale/sale are considered. To do so, we collected 2074 completed questionnaires on energy consumption that entered an econometric model using propensity score matching to control for estimation biases. We find significant differences in the willingness to consume electricity in a flexible manner for (co-)owners of solar installations. However, only the usage of household appliances proves to be statistically significant (p-value = 0.04). Furthermore, the results show that within the group of (co-)owners of solar installation, the choice between self-consumption and sale of the produced energy has a significant effect on the inclination to become demand flexible (p-value ≤ 0.001; p-value = 0.003).

Keywords: renewable energy; consumer ownership; demand flexibility; demand side management; propensity score matching; solar energy

1. Introduction

Producing energy from renewable sources has gained increasing support in Europe and throughout the world. The authors of [1] predict that the largest share of capacity increase in the years to come will be shouldered by photovoltaic (PV) installations and wind turbines. In their market analysis and forecast from 2018 to 2023, PV and wind power alone will account for approximately 75 percent of growth in the renewable energy (RE) sector. (This article focuses solely on electric energy). The abbreviation RE therefore means exclusively renewable energy in terms of electricity production.

The volatile nature of both technologies poses numerous technical and economic challenges. From an infrastructure perspective, the predominantly centralized electricity grid systems run into difficulties when loads vary in short intervals and with significant values, e.g., rapid declines or increases in power production, for instance, when wind

turbines or PV installations cannot produce as forecasted due to unexpected weather changes. A constant baseload from fossil energy sources can stabilize the grid system and mitigate critical events triggered by volatile renewable energy sources (vRES) that threaten to impair grid stability [2]. However, this solution conflicts with the declared political aim of an ever-increasing market penetration of renewables in the European Union [3]. Furthermore, under this approach, coping with an increasing amount of vRES in the electricity mix also requires the capability of quick reaction which strongly increases the overall system cost due to a combination of low operation times and high per unit production cost of the most flexible backup generation technologies, for instance, of modern gas turbines [4]. From an economic perspective, cumulated production amounts of vRES cause market-related challenges. If the share of available energy in domestic or international energy markets fluctuates unexpectedly, energy prices follow common market laws. The invert relationship between price and supply results in dramatically depleting, sometimes even negative, electricity prices in cases of unexpected oversupply caused by weather changes, that are often difficult to predict. Regulation to incentivize renewables, such as priority dispatch of renewables into the grid, worsens the resulting economic inefficiency [5]. Given the latest political endorsement for PV and wind energy in major economies, both effects are expected to worsen if not controlled for as the share of vRES is on the rise in the foreseeable future [1].

One possibility to mitigate both effects described above is to apply a broad spectrum of demand side management (DSM). DSM comprises all measures (e.g., flexibilization of demand) undertaken on the consumption side to stabilize the grid system. Strategies for promoting sustainable behavior and flexible demand are manifold.

The involvement of citizens in community energy projects is often mentioned as a particularly promising approach. The underlying rationale is that the direct participation of citizens in energy projects through (co-)ownership deepens the personal involvement with questions of energy consumption and thus promotes sustainable behavior suitable to support the infrastructure system.

Initial findings from research in this context show that there is a link between the role of being a (co-)owner in energy projects and personal energy consumption behavior [6,7]. However, these studies share that the characteristic of (co-)ownership is only examined without differentiating according to the underlying technology used to produce RE. Nonetheless, the type of installation deserves special attention as available technologies differ regarding background characteristics, such as the technical complexity of the operation or the spatial proximity between energy production and consumption. For example, solar energy systems are easier to handle during operation than wind power plants and production as a rule takes place closer to consumption in particular with rooftop systems [8]. This paper takes up those technological differences. The research goal is to deepen the growing body of literature on demand side management and analyze the question whether there is a relationship between (co-)ownership of renewable energy production facilities, the applied technology, and energy consumption behavior. To do so, an empirical analysis with propensity score matching methodology is applied.

2. Literature Review

The sustainability and security of economic development around the globe are based on the smooth and uninterrupted supply and demand mechanisms of energy sources [9]. The current stage of the international energy sector transformation is characterized by a growth in demand for energy supply and intensified use of renewable energy sources (RES) resulting in a higher fluctuation of energy supply and technical challenges stemming thereof [10]. To deal with the challenge of providing stability and flexibility to energy systems that include a high proportion of vRES, several strategies involving utilities, grid operators, regulatory bodies, policy-makers, and consumers are pursued. These strategies can be distinguished into three main categories: energy efficiency (EE), on-site back-up systems, and flexibilization. In this context, flexibilization, i.e., measures

that encourage consumers to load shifting, is considered as particularly attractive as it mainly relies on capacities that already exist and therefore is theoretically easy to implement [11]. While the effectiveness of flexibilization at the demand side in general is debated, given an increasing share of vRES, the bulk of research and practical experience supports its advantages and suitability to contribute to support infrastructure stability [12–15]. Approaches to systematically characterize DSM measures identify strategies which include among others technical strategies such as remote control or in-home displays for load and consumption transparency [16,17], dynamic pricing strategies to promote demand response [18], information campaigns for energy consumers, e.g., the diffusion of good practices, and regulatory measures, like utility obligations, product standards, and product labeling [15] with all of these strategies being able to operate on the household and the industrial sector level.

When focusing on DSM at the household level, various factors can be used as triggers to bring private consumers to apply demand side measures. A widely discussed approach in the scientific discourse and energy industry practice is to equip households with smart appliances and face them with variable electricity prices. These variable pricing schemes can be time-based (see, e.g., in [19–21]) or schemed to optimize distribution grid services [22,23]. A second approach focuses on the provision of information through traditional communication channels such as information brochures and billing letters or smart meter devices in order to promote flexible behavior (see, e.g., in [24,25]). The provision of information has in general been proven to be an effective measure to induce changes in energy consumption behavior and people's opinion towards renewable energy [26]. Another factor that can be used to bring private consumers to apply demand side measures is the appeal to norms. In this context, aspects such as environmental concern are tested to enable load-shifting (and other energy conservation behaviors) among end users with mixed results on the actual efficacy of such measures (see, e.g., in [27–29]). In line with this rather psychological approach, Frederiks et al. [30] explained energy consumption behavior with biased perception, consumer heuristics, and other irrational inclinations. Furthermore, other cognitive and contextual factors can have an influence on an individual's behavior in the context of energy-related topics and therefore also in the context of electricity consumption and demand flexibility. These factors include the awareness of the problem, e.g., an individual's understanding and knowledge on energy-related questions such as grid stability and supply security; nuances of media coverage, e.g., the variety of information sources and its evaluation; and finally, trust in the energy system's stability [31]. Accordingly, much more attention should be given to these aspects when analyzing the behavioral aspects of energy consumption [32]. In this context, business models involving citizens as (co-)owners of RE and thus as prosumers are of particular interest as they combine several possible influences on an individual's energy consumption. These business models, often referred to in the literature as community energy (see, e.g., in [33]) or citizen energy (see, e.g., in [34]), either involve citizens in project planning and financing with self-consumption having a subordinate role, or they explicitly foster prosumership and address several of the above-mentioned triggers to promote demand flexibility [35]. Therefore, the behavior of energy consumers involved in citizen energy projects has been the focus of various scientific papers. Among others, Anda and Temmen [36] find that community-based social marketing has shown to be very effective at inducing behavioral change towards a more efficient and flexible energy use. Another study from Hoppe et al. [37] shows that in addition to psychological and socio-demographic variables, the characteristic framework of an energy cooperative, as a particular business model for citizen energy, can contribute to more engagement in energy-saving actions and reported energy conservation. Another approach by Goulden et al. [38] revealed that citizen participation in energy production and energy consumption holds great potential for various kinds of DSM measures in a non-commercial context. Further, the authors of [7] showed that different prosumption options

for produced electricity impact demand flexible behavior as well, depending on whether produced electricity can be used for self-consumption, sale, or both.

However, all these papers have a restriction in common, i.e., the participants of citizen energy projects are analyzed as a homogenous group in comparison to non-participants without any further distinction of the type of RE conversion technology they are invested in, be it PV, wind, or bioenergy. Kubli et al. [6] discuss the technological background to a limited extent when they showed that people who own PV installations or electric vehicles are more likely to adapt DSM, indicating a relationship between energy technologies and consumption behavior. This study, however, focuses on three different application areas of RE technologies, being photovoltaic heat pumps and electric vehicles, i.e., electricity production, heating, and transportation. Extending and deepening this analysis with regard to other types of RE is important, as the preceding studies show that the application of green technologies is expected to allow for and trigger different behavior. Moreover, conversion technologies have inherently different characteristics that hold potential for various, behavioral implications. For instance, PV systems when compared to wind farms (in particular, offshore), are generally located closer to the prosumer, are smaller in terms of installed capacity requiring smaller investments per unit and offer individual control. The authors derive the leading research hypotheses on this basis.

When looking at RE conversion technologies, biomass, hydropower, geothermal, tidal/wave, solar, and wind energy are identified as technologies with the highest potential to substitute fossil fuels [39]. Among those technologies, biomass, wind, and solar energy have the largest potential in terms of installed capacity and are expected to be the most prevalent in the future [40], which is why the following analysis focuses on these technologies. Drawing on results of the data analysis the authors combine the two aspects of conversion technology and prosumption options to refine the picture further. Availability of data permitting, each conversion technology is analyzed in association with the three options to use electricity produced, i.e., (i) self-consumption, (ii) sale to third parties, and (iii) the choice between self-consumption and sale.

Regarding the conversion technology, in line with the work in [6], it is assumed that people who (co)-own solar power plants are inclined to be more willing to exercise demand flexible behavior than the other groups. Further, in line with Goulden et al. [38], a general involvement in RE in other technologies is expected to trigger a more flexible consumption as compared to no involvement.

For further analyzation, the following abbreviations for group affiliation were used throughout the manuscript:

- Non-owners　　　　　People who are not involved with RE;
- Solar-owners　　　　People who (co-)own a solar energy power plant;
- Wind-owners　　　　People who (co-)own a wind turbine;
- Biogas-owners　　　People who (co-)own a biogas power plant.

At the meta-level, the authors formulate two main hypotheses (A and B) regarding the used conversion technology and prosumption options:

Hypothesis A (HA). *(Co-)ownership in renewable energy production facilities positively impacts a consumers' willingness to use electricity in a flexible manner. Solar installations hold the largest potential to trigger flexibility in this regard.*

This breaks down into six sub-hypotheses:

Hypothesis 1 (H1). *Solar-owners are more willing to be demand flexible than Non-Owners.*

Hypothesis 2 (H2). *Wind-owners are more willing to be demand flexible than Non-Owners.*

Hypothesis 3 (H3). *Biogas-owners are more willing to be demand flexible than Non-Owners.*

Hypothesis 4 (H4). *Solar-owners are more willing to be demand flexible than Wind owners.*

Hypothesis 5 (H5). *Solar-owners are more willing to be demand flexible than Biogas owners.*

Hypothesis 6 (H6). *Wind-owners are more willing to be demand flexible than Biogas owners.*

Hypothesis B (HB). *The consecutive hypotheses regarding the technology in association with different options to use the produced energy depend on the results of H1–H6 as well as the availability of data. Therefore, the respective hypotheses system will be built up after analyzing H1–H6.*

3. Methodology

The following chapters give a brief overview of the sampling process, specifications on measurement, and statistical procedure.

3.1. Deliberations on Data Collection

The study was conducted in cooperation with the website www.immobilienscout24.de. The sample was obtained via an online survey using the data base of this website. ImmobilienScout24 is the biggest online real estate platform in Germany. The user base of 14.8 million monthly visitors [41] provides perfect conditions to obtain a representative high-quality sample containing participants holding demographics close to those of the German population. At the same time, it was important to reach a sufficient number of people of interest to this analysis, i.e., (co-)owners of RE production facilities, to enable the researchers to apply the underlying econometric approach which, in this instance, requires a large sample size (cf. Section 3.4). As a real estate platform, the ImmobilienScout24 data base is likely to hold a large share of users which own real estate. The probability of homeowners being involved with energy related questions (e.g., production, self-sufficiency, and energy efficiency) is higher than with typical consumer panels holding less people who live in own property [42].

The participants were invited via e-mail to take part in the study. The invitation text specifically mentioned purposes and involved institutions in the analyzation of the data. In total, the sample consisted randomly chosen users of 135,000 users who have an account with ImmobilienScout24. 4315 potential participants had to be excluded because of personal e-mail settings or technical restriction (Users of the website can restrict their e-mail settings as to not receive any e-mails from ImmobilienScout24. In this case the e-mail addresses had to be excluded. Technical problems can be, for instance, a full e-mail inbox, not existing or deactivated domain). To motivate the participants to complete the whole questionnaire, 5 Amazon vouchers were raffled. Doing so increases the response rate and statistical power in terms of representativity [43,44]. Ultimately 130,685 invitation e-mails were sent which resulted in 2074 completed questionnaires which entered the analysis. The response rate is in line with ordinary expectation for online surveys where people do not expect an e-mail invitation for a study [45–47]. Answers from participants who did not finish the questionnaire might yield bad data quality [48]. Therefore, only completed questionnaires were included in the analysis.

3.2. Deliberations on Measurement

To analyze the hypothesis, in a first step, the groups of interest must be distinguished. To do so, the questionnaire included questions regarding a participant's involvement in RE production (the Questionnaire flow, i.e., a summary of all the questions the participants had to go through is depicted in Appendix A. The full version of the questionnaire is depicted in Appendix B. Please note that the original questionnaire was in German. Under each questionnaire screenshot an English translation can be found). Further, to determine a personal level of demand flexibility the participants had to rate their willingness to consume energy in a flexible way for three different electricity consumption settings on a Likert scale possible answers being graded from 1 for "I strongly disagree" to 5 "I strongly agree". The electricity consumption settings were chosen after a literature analysis that the questionnaire was based on. Possibilities for demand flexibility are discussed in several domains. For instance, Firth et al. [49], Naus et al. [50], and Moser [51] highlight the importance of household appliances and mobile

electrical devices. Further, Kubli et al. [6] and Pallonetto et al. [52] underline the inclusion of electrical means of transportation for load shifting approaches. Consequently, the following individual electricity consumption settings were selected:

I am willing to…

… use household appliances (e.g., washing machine, dishwasher, etc.) mainly when the share of electricity from renewable sources in the grid is very high.

… recharge electrical devices (e.g., laptop) mainly when the share of electricity from renewable sources in the grid is very high.

… recharge electrical means of transportation (e.g., electric car/scooter/bike) mainly when the share of electricity from renewable sources in the grid is very high.

The rated answers to those dimensions are the basis to calculate a measure for demand flexibility in different domains and compare it among the defined research groups. A complete data summary and codebook of all used variables to test the hypotheses can be found in Tables A1 and A2 in Appendix C.

3.3. Deliberations on the Sample

Using an explorative approach, the data quality of the sample was evaluated. A series of pre-tests revealed that it was not possible to seriously answer all questions when spending less than 4 min on the questionnaire; the questionnaire software automatically discarded those cases, resulting in an initial data set of 2143 completed questionnaires. The evaluation further revealed that some participants gave inconsistent answers by clicking back and forth in the questionnaire. Therefore, in a second step, cases were manually excluded if participants gave contradictory answers (for instance, a participant selected "yes" with an involvement in RE, answered all consecutive questions on the RE installation, but then went back to the first question and altered the answer for the involvement with RE to "no".). To avoid any contextual and statistical ambiguities, participants who (co-)own more than one installation in different technological domains or select the "else" (for instance, participants indicated that they participate renewable energy production projects. When they are asked in which way they are involved they gave answers like and gave an answer in the free text field next to the) option and thereby indicating a technology, which was not relevant for the analysis, were excluded from the analysis as well. In doing so, ultimately, a sample of 2074 was used to test the hypotheses. The Table A3 in Appendix D depicts the data cleaning process with the respective number of deleted cases in each step.

3.4. Deliberations on the Model Specification

A statistical analysis with the aim to examine differences in groups on a specific target variable is prone to suffer from estimation biases. Biases arise with general differences in characteristics of the research groups. In this instance, specific biases could result from the non-random sampling procedure (online survey). Therefore, the reference groups could have fundamentally different predispositions which influence the dependent variable (here demand flexibility) rather than being a (co-)owner. To control for estimation biases, a matching procedure is applied. Matching can be used in a variety of scenarios when comparing groups on a dichotomous variable (here being a (co-)owner of a certain technology with a subsequent usage possibility of produced energy). The aim is to artificially randomize the sample by homogenizing the comparison groups; in other words, to make them comparable on demographic covariates. The matching itself is based

on different initial characteristics of the participants. To applied matching technic must ensure the highest similarity possible of those characteristics in both groups.

In those instances, propensity score matching (PSM) has proven to be a reliable approach for observational studies in general (see, e.g., in [53,54]) and web-surveys in specific (see, e.g., in [55–57]). PSM was developed by Rosenbaum and Rubin [58]. It channels all relevant characteristics into an individual score for each participant reflecting the probability of belonging to a certain group. Subsequently, the matching procedure is run based on the individual scores.

To execute the described PSM, in a first step, it is necessary to identify crucial characteristics of the participants that influence their probability on being involved with RE. A statistical approach to do so is a logistic regression that estimates the influence of categorical or continues independent variables on a binary outcome variable, in this instance being a (co-)owner or not. The regression was run using all available demographics (cf. data summary in Appendix C). A summary of the regression results is depicted in Table A4 in Appendix D. The procedure revealed that gender, age, net income, and population of the city/village have a significant impact on whether people are (co-)owners of renewable energy production facilities. Therefore, they enter the model as independent variables to calculate the propensity score.

To ensure an evenly balanced influence of all predictors when calculating the propensity scores, the varying scale levels were unified by applying a standardized z-score. Equation (1) describes this procedure.

$$z = \frac{x - \mu}{\sigma} \tag{1}$$

z corresponds to a demographic variable after the standardisation. x stands for the original scale value from a single participant and μ is the sample mean of variable x. σ corresponds to the standard deviation of the sample for variable x. In summary, one subtracts the sample mean μ from the original scale value x and divides this result by the standard deviation σ of the sample [59]. This procedure is run for all demographic variables for each participant.

The propensity score was calculated using pscore syntax in Stata 16. Equation (2) depicts a generic model that was run for each of the hypotheses. It describes the procedure on how the propensity score is estimated using a probabilistic model.

$$Treatment = \left(\frac{P_i}{1 - P_i}\right) = \beta_0 + \beta_1 Gender + \beta_2 Age + \beta_3 NetIncome + \beta_4 Location + \varepsilon_i \tag{2}$$

$\left(\frac{P_i}{1 - P_i}\right)$ corresponds to the outcome variable for observation i. β_1 to β_4 stand for the slope coefficients for gender, age, net income, and location (meaning the population in the respective city/village). ε_i is an error term loaded with other variables that might influence the propensity score.

After the scores are calculated, different matching techniques are available to mathematically form treatment and control group. In this paper, the authors decided to apply the commonly used nearest neighbor algorithm. When calculating the mean difference of the outcome variable, i.e., the Average Treatment Effect on the Treated (ATT), a sufficient common support must be ensured to evaluate the influence that group affiliation has on demand flexibility.

As often the case with observational studies, the data at hand are skewed towards the positive end of the outcome variable. This circumstance leads a violation of the normality assumption with parametric test procedures, such as a simple mean comparison. To account for the lack of normality of the data a nonparametric bootstrap is applied. When using the bootstrap, no specific distribution is assumed. Rather the distribution of the outcome variable is estimated through a resampling procedure. To do so, one needs to draw new samples from the original sample (resampling). The resulting empirical distribution function can be used to obtain confidence intervals and related

hypotheses test without the requirements of normality, equality of variances or specific distribution shapes [60]. Equations (3) and (4) show an exemplary resampling procedure. The process is described as

$$E \rightarrow x = (x_1, x_2, ..., x_n) \rightarrow T(x) \tag{3}$$

with the unknown distribution E, the random sample x as well as the outcome variable $T(x)$ where one draws n times with replacement from $(x_1, x_2 ..., x_n)$ to generate the bootstrap sample

$$\hat{E} \rightarrow x^* = (x_1^*, x_2^*, ..., x_n^*) \rightarrow T(x^*) \tag{4}$$

with the empirical distribution $\hat{E}$ of the bootstrap sample x^* the outcome variable $T(x^*)$ based on the empirical distribution. It is vital to set a sufficient number of sampling repetitions which is usually reached when a further increase does not change $T(x^*)$. To guarantee a maximum level of security, the above-mentioned procedure is run 5000 times, which is in line with recommendations from scientific literature [61,62]

4. Results and Hypothesis Testing

The results section is structured according to hypotheses that compare (i) demand flexibility along the form of participation and subsequently (ii) demand flexibility within the group of consumers that (co-)own PV installations along the usage possibilities of the produced energy. All hypotheses were tested using the matching technique described in Section 3.4. The defined specifications yield consistent diagnostics showing significant PSM estimates throughout all test scenarios. Additionally, for all specifications that yield results the assumption of common support is maintained. The latter is a prerequisite for the second step of the test procedure, i.e., the calculation of the ATT, for all defined specifications. A hypothesis is preliminary confirmed if the error probability is below 5 percent ($\alpha = 0.95$).

4.1. Comparison According to Type of Renewable Energy Source

The first six hypotheses look at differences in demand flexible behavior based on the type of energy source the consumer (co-)owns. The considered types of RES are solar power plants, wind turbines, and biogas plants. Thereby, the different RE conversion technologies are compared among each other as well as with consumer who are not involved with Renewables at all.

H1. *Solar owners are more willing to be demand flexible than non-owners.*

All analyzed dimensions of demand flexibility are depicted in Table 1. Each dimension holds values for the group size of treated and controls in the column observations (OBS). The ATT corresponds to the mean difference between the groups. Additionally, the t- and *p*-value, respectively, indicate whether the observed treatment effect is significant. To partially confirm a hypothesis the *p*-value must be smaller than 0.05, i.e., below the previously defined error probability of 5 percent.

For H1 the treatment group consists of consumers who are (co-)owners of a solar installation (solar owners) and the controls are consumers who are not involved with RE (non-owners). Throughout all dimensions, the results show that people who (co-)own solar installations tend to be more demand flexible than people who are not involved with RE. However, only the first dimension, the usage of household appliances proves to be statistically significant. In average, solar owners are 0.231** scale points more willing to be demand flexible when compared to non-owners. The mean differences for charging of other electrical appliances as well as electrical means of transportation amount to 0.060 and 0.084, respectively. Therefore, they are rather small and have to be discarded as insignificant. Therefore, H1 is partially confirmed. Based on the underlying data, it can be concluded that people who are (co-)owners of a solar installation are in average more

willing to be demand flexible than people who have no junction to the production of energy from renewable sources but only when looking at the usage of household appliances.

Table 1. Demand flexibility comparisons of solar owners (treated) versus non-owners (controls) (source: authors' own calculations). Note: *'s denote statistical significance levels (*** 1 percent; ** 5 percent).

Dimension	Group	OBS	Mean	ATT	t-Value	p-Value
Usage of household appliances	Treated	218	3.612 [1]	0.231 **	1.722	0.043
	Controls	670	3.382			
Charging electrical appliances	Treated	218	3.114	0.060	0.402	0.344
	Controls	671	3.054			
Charging electrical means of transportation	Treated	218	3.489	0.084	0.548	0.292
	Controls	572	3.405			

[1] Differences between depicted means and ATT can occur due to applied rounding rules; statistics software considers six decimal places.

H2. *Wind owners are more willing to be demand flexible than Non-owners.*

H2 looks at the differences between people who are involved with RE production from wind turbines (wind owners) as the treated group and non-owners as controls. Following the calculated ATT (Table 2), the wind owners are more willing to be demand flexible; at least from a descriptive perspective. The mean difference for the usage of household appliances, in this instance, amounts to 0.210 scale points. The biggest ATT can be observed with the charging of other electrical appliances and amounts to 0.362. For the charging of electrical means of transportation, the average mean difference equals 0.140. However, throughout all dimensions, the *p*-value is bigger than 0.05. Therefore, all results are statistically not significant and must be discarded. In the context of this study, there is no difference in the willingness to be demand flexible between people who (co-)own wind turbines and people that are not involved with RE.

Table 2. Demand flexibility comparisons of Wind-owners (treated) versus Non-Owners (controls) (source: authors' own calculations).

Dimension	Group	OBS	Mean	ATT	t-Value	p-Value
Usage of household appliances	Treated	20	3.850	0.210	0.511	0.305
	Controls	92	3.640			
Charging electrical appliances	Treated	20	3.350	0.362	0.781	0.218
	Controls	92	2.988			
Charging electrical means of transportation	Treated	20	3.400	0.140	0.335	0.369
	Controls	82	3.260			

H3. *Biogas-owners are more willing to be demand flexible than Non-owners.*

The third hypothesis compares the willingness to be demand flexible from people who are (co-)owners of a biogas plant (Biogas-owners) against Non-owners. The former represents the treatment, whereas the latter serve again as controls. The analysis of H3 reveals that from a descriptive perspective Biogas-owners tend to be less demand flexible than Non-owners (Table 3). The ATT for the usage of household appliances indicates that Biogas-owners are on average 0.408 scale points less demand flexible than Non-owners within the scope of the usage of household appliances. The mean difference for the charging of other electrical appliances is with −0.092 less severe. The largest ATT can be observed with the charging of electrical means of transportation and amounts to −0.667. Regardless of the negative tendencies, all results yield insufficient t-values and therefore

must be discarded as insignificant. In this instance, it is important to note that the number of observations in both groups is rather low. This circumstance limits the explanatory power of the whole H3. Nevertheless, within the scope if this analysis, the H3 must be utterly rejected. There is no difference in the willingness to be demand flexible for people who (co-)own a biogas plant and those who are not involved with RE.

Table 3. Demand flexibility comparisons of Biogas-owners (treated) versus Non-Owners (controls) (source: authors' own calculations).

Dimension	Group	OBS	Mean	ATT	t-Value	p-Value
Usage of household appliances	Treated	5	3.400	−0.408	−0.379	0.354
	Controls	17	3.808			
Charging electrical appliances	Treated	5	3.000	−0.092	−0.084	0.467
	Controls	17	3.092			
Charging electrical means of transportation	Treated	5	3.200	−0.667	−0.641	0.265
	Controls	15	3.867			

H4. *Solar-owners are more willing to be demand flexible than Wind-owners.*

H4 considers differences in expressed willingness to behave in a demand flexible manner between Solar-owners (treated) and Wind-owners (controls). The ATT indicates a negative treatment effect in all analyzed dimensions (Table 4). For the usage of household appliances, the average mean difference between Solar-owners and Wind owners amounts to −0.864 scale points in favor of the latter. The ATT for the charging of electrical appliances is −0.600. The average mean difference for electrical means of transportation is with −0.266 the smallest. Even though, one observes a tendency that Wind-owners are more willing to be demand flexible than Solar-owners, all dimensions yield insufficient t- and corresponding *p*-values. The observable tendencies are all statistically insignificant.

Note that the group sizes are unequal to a large extent and the number of observations for people who (co-)own wind turbines is rather small. Both circumstances have a destabilizing effect on the applied testing procedure and need to be evaluated when discussing the results. In the context of this study, there is no difference in willingness to apply demand flexible behavior between people who (co-)own solar installations and wind turbines. H4 must be utterly rejected.

Table 4. Demand flexibility comparisons of Solar-owners (treated) versus Wind-owners (controls) (source: authors' own calculations).

Dimension	Group	OBS	Mean	ATT	t-Value	p-Value
Usage of household appliances	Treated	218	3.077	−0.864	−1.129	0.130
	Controls	18	3.941			
Charging electrical appliances	Treated	218	3.096	−0.600	−0.765	0.223
	Controls	18	3.696			
Charging electrical means of transportation	Treated	218	3.149	−0.266	−0.351	0.363
	Controls	14	3.415			

H5. *Solar-owners are more willing to be demand flexible than Biogas-owners.*

The H5 tries to analyze differences in consumption behavior between Solar-owners (treated) and Biogas-owners (controls). However, the analyzation of this particular hypothesis proves to be difficult. In this instance, the treated group contains 218 people who (co-)own solar installations (Table 5). On the other hand, the whole sample solely contains six observations which are (co-)owners of a biogas plant. In the course of the matching procedure, only one observation meets the requirement of common support and

enters the analysis. Even though the bootstrap allows to calculate the statistics of interest for the first two dimensions, the interpretation of the results does not make sense due to the insufficient number of cases. In conclusion, differences in consumption behavior between (co-)owners of Solar-installations and biogas plants cannot be analyzed with the data at hand.

Table 5. Demand flexibility comparisons of Solar-owners (treated) versus Biogas-owners (controls) (source: authors' own calculations). Note: *'s denote statistical significance levels (*** 1 percent; ** 5 percent).

Dimension	Group	OBS	Mean	ATT	t-Value	p-Value
Usage of household appliances	Treated	218	3.000	−2.000 ***	−5.806	<0.001 [1]
	Controls	1	5.000			
Charging electrical appliances	Treated	218	4.000	−1.000 **	2.201	0.014
	Controls	1	3.000			
Charging electrical means of transportation[2]	Treated	218	-	-	-	-
	Controls	1	3.000			

[1] Please note: the authors report <0.001 if the calculated t-value is smaller than 0.001. [2] The third dimension does not yield a result because the only matched treated observation does not hold a value, i.e., has selected "I don't know" for this question.

H6. *Wind-owners are more willing to be demand flexible than Biogas-owners.*

In H6, the authors want to compare the willingness to be demand flexible of Wind-owners (treated) and Biogas-owners (controls). Both groups contain solely 21 and six observations each in the same order (Table 6). The 20 observations viable for matching as treated cannot be matched with any of the six observations who (co-)own biogas plants without violating the diagnostic restrictions. Therefore, similar to the previous hypothesis, the data do not allow analysis of H6. In the context of this study, one cannot analyze whether or not the willingness to apply demand flexibility measures differs between (co-)owners of a wind turbine or a biogas plant.

Table 6. Demand flexibility comparisons of Wind-owners (treated) versus Biogas-owners (controls) (source: authors' own calculations).

Dimension	Group	OBS	Mean	ATT	t-Value	p-Value
Usage of household appliances	Treated	20	-	-	-	-
	Controls	-	-			
Charging electrical appliances	Treated	20	-	-	-	-
	Controls	-	-			
Charging electrical means of transportation	Treated	20	-	-	-	-
	Controls	-	-			

Summary H1–H6

H1 to H6 analyze the differences in reported willingness for demand flexible behavior according to the type of RES a consumer (co-)owns. Thereby, comparisons among (co-)owners of solar installations, wind turbines, biogas plants, and people who are not involved with RE are undertaken. Significant differences in the willingness to consume electricity in a flexible manner were solely found when comparing (co-)owners of solar installations with people who do not (co-)own RE production facilities. However, the comparison within different forms of RES in H5 and H6 do not yield viable results due to an insufficient number of cases in each group. The statistical power of the comparisons in H3 (Biogas-owners versus Non-owners) and H4 (Solar-owners versus Wind-owners is also weak due to an unequal distribution of cases as well as a limited number of observations for the Wind-owners.

Regardless of the limitations above, the data allow us to conclude that statistical differences with regard to the willingness to be demand flexible occur when comparing people who are (co-)owners of solar installations with people who have no touchpoints with RE production. That is, it seems that to trigger demand flexible behavior, solar installations are a viable option.

4.2. Comparison According to the Usage Possibilities within (Co-)Owners of Solar Power Plants

The following chapter links this finding of a previous work in [7] where the authors presented empirical evidence that (co-)ownership in RE installations does solely trigger a change in a consumer's behavior if the (co-)owners have the possibility to consume as well as sell energy to the grid at the same time. Given the previously presented results—solar installations being the only RES that goes hand in hand with a significant difference in the willingness to be demand flexible—it is logical to combine both metrics, i.e., analyze differences in the willingness to be demand flexible among, people who are (co-)owners of solar installations and solely consume, consume as well sell at the same time, solely sell and people who are not involved in energy production from renewable sources at all. As already stated, at this point, due to the lack of data a subdivision of other analyzed technologies, i.e., wind and biogas, into the different usage possibilities is statistically not senseful.

For further analyzation, the following abbreviations for group affiliation in terms of energy usage options were used throughout the manuscript:

- Non-owners   People who are not involved with RE;
- Solar-consumers   People who (co-)own solar installations and solely consume produced RE;
- Solar-consellers People who (co-)own solar installations and consume as well as sell RE at the same time;
- Solar-sellers   People who (co-)own solar installations and solely sell produced RE.

Returning to the 2 meta-level hypotheses from Section 2, the following second main hypothesis is analyzed.

Hypothesis B (HB). *Only the prosumption option of consuming and selling produced electricity from solar installations at the same time positively impacts a consumers' willingness to use electricity in a flexible manner.*

This breaks down into six sub-hypotheses:

Hypothesis 7 (H7). *Solar-consumers (are more willing than Non-owners.*

Hypothesis 8 (H8). *Solar-consellers are more willing than Non-owners.*

Hypothesis 9 (H9). *Solar-sellers are more willing than Non-owners.*

Hypothesis 10 (H10). *Solar-consellers are more willing than Solar-consumers.*

Hypothesis 11 (H11). *Solar-consellers are more willing that Solar-sellers.*

Hypothesis 12 (H12). *Solar-sellers are more willing than Solar-consumers.*

H7. *Solar-consumers are more willing to be demand flexible than Non-owners.*

H7 compares differences in intended consumption behavior between people who solely consume energy produced by their solar installations (Solar-consumers) and people who are not involved with RE (Non-owners). The treatment is assigned to the Solar-consumers and the Non-owners serve as controls. The ATT point jointly towards a negative direction for all analyzed dimensions (Table 7). The mean difference for the usage of household appliances is 0.034 scale points smaller in the group of the Solar-consumers as opposed to the Non-owners. The biggest difference can be observed with the charging of other electrical appliances and amounts to −0.120 scale points. Last, the smallest

difference is −0.011 scale points and can be found with the charging of electrical means of transportation. Even though, one observes a tendency that the Solar-consumers are less flexible in their demand than Non-owners throughout all dimensions, all results have to be discarded as insignificant. H7 must be rejected. In this analysis, there is no difference in the expressed willingness to be demand flexible between people who (co-)own solar installations and people who are not involved with RE production.

Table 7. Demand flexibility comparisons of Solar-consumers (treated) versus Non-owners (controls) (source: authors' own calculations).

Dimension	Group	OBS	Mean	ATT	t-Value	p-Value
Usage of household appliances	Treated	128	3.347	−0.034	−0.191	0.424
	Controls	509	3.381			
Charging electrical appliances	Treated	128	2.976	−0.120	−0.674	0.250
	Controls	510	3.096			
Charging electrical means of transportation	Treated	128	3.386	−0.011	−0.057	0.477
	Controls	442	3.397			

H8. *Solar-consellers are more willing to be demand flexible than Non-owners.*

H8 looks at differences in expressed willingness to be demand flexible between (co-)owners of solar installations who have the possibility to consume as well as sell energy at the same time (Solar-consellers) and Non-owners. The ATT are jointly positive, meaning Solar-consellers have higher average means on the flexibility scale than Non-owners (Table 8). For the first dimension—the usage of household appliances, the ATT amounts to 0.909 scale points. In this instance, the *p*-value is reported to be below 0.001, which corresponds to a highly significant result. For the charging of other electrical appliances, the mean difference is 0.442. The *p*-value amounts to 0.073 and is slightly above the allowed error probability of 5 percent. The ATT for the charging electrical means of transportation is with 0.370 the smallest and with a *p*-value of 0.140 an insignificant result. Nevertheless, H8 can be partially confirmed. In this study, there is a significant difference in the willingness to be demand flexible between (co-)owners of solar installations and consumers who are not (co-)owners of RE production facilities when looking at the usage of household appliances.

Table 8. Demand flexibility comparisons of Solar-consellers (treated) versus Non-owners (controls) (source: authors' own calculations). Note: *'s denote statistical significance levels (*** 1 percent; ** 5 percent).

Dimension	Group	OBS	Mean	ATT	t-Value	p-Value
Usage of household appliances	Treated	47	4.130	0.909 ***	3.545	<0.001
	Controls	191	3.222			
Charging electrical appliances	Treated	47	3.356	0.442	1.459	0.073
	Controls	194	2.914			
Charging electrical means of transportation	Treated	47	3.538	0.370	1.085	0.140
	Controls	162	3.169			

H9. *Solar-sellers are more willing to be demand flexible than Non-owners.*

With H9 the comparison between people who (co-)own solar installations and solely sell energy they produce from those installations (Solar-sellers) and Non-owners is undertaken. The former represents the treated and the latter the control group. The ATT show higher average mean differences in favor of the Solar-Sellers in all dimensions (Table 9). In detail, the ATT for the usage of household appliances is 0.193. The mean difference for charging other electrical appliances is 0.136. Last, the difference in average means for

electrical means of transportation amounts to 0.244. Based on those results, there is a tendency that Solar-Sellers are more willing to be demand flexible than Non-owners. However, the reported results are utterly insignificant. Therefore, the H9 is rejected. In this analysis, there is no statistical differences in the willingness to be demand flexible between people who (co-)own solar facilities and people who are not involved with RE.

Table 9. Demand flexibility comparisons of Solar-sellers (treated) versus Non-owners (controls) (source: authors' own calculations).

Dimension	Group	OBS	Mean	ATT	t-Value	p-Value
Usage of household appliances	Treated	43	3.810	0.193	0.671	0.251
	Controls	188	3.616			
Charging electrical appliances	Treated	43	3.262	0.136	0.382	0.351
	Controls	187	3.126			
Charging electrical means of transportation	Treated	43	3.722	0.244	0.784	0.217
	Controls	165	3.478			

H10. *Solar-consellers are more willing to be demand flexible than Solar-consumers.*

In the course of H10, Solar-Consellers (treated) are compared with Solar-Consumers (controls). With 1.242, the largest ATT reported so far occurs with the usage of household appliances (Table 10). This result is highly significant and holds an error probability below 1 percent. With the charging of other electrical appliances, the mean difference amounts to 0.685 scale points. However, in this instance, the corresponding *p*-value of 0.074 shows that this result is insignificant by a narrow margin. The last dimension—charging of other electrical appliances—yields an ATT of 0.584 and a *p*-value of 0.148, an insignificant result as well. Following the presented results H10 can be partially confirmed. Electricity consumers who (co-)own solar energy production facilities are more willing to be demand flexible than consumers who (co-)own solar energy production facilities and solely consume the energy they produce. This, however, holds only true for the usage of household appliances.

Table 10. Demand flexibility comparisons of Solar-consellers (treated) versus Solar-consumers controls) (source: authors' own calculations). Note: *'s denote statistical significance levels (*** 1 percent; ** 5 percent).

Dimension	Group	OBS	Mean	ATT	t-Value	p-Value
Usage of household appliances	Treated	47	4.100	1.242 ***	2.786	0.003
	Controls	39	2.858			
Charging electrical appliances	Treated	47	3.410	0.685	1.461	0.074
	Controls	40	2.725			
Charging electrical means of transportation	Treated	47	3.412	0.584	1.051	0.148
	Controls	32	2.828			

H11. *Solar-consellers are more willing to be demand flexible than Solar-sellers.*

H11 compares the expressed demand flexibility of Solar-consellers (treated) and Solar-seller (controls). The ATT depicts a varying picture (Table 11). For the usage of household appliances, it amounts to 0.479. In the case of the charging of other electrical appliances, an ATT of −0.153 is reported, meaning Solar-consellers are slightly less demand flexible than Solar-sellers. In the last analyzed dimension, the charging of electrical means of transportation, the average mean difference is 0.214 scale points in favor of the Solar-consellers. Nonetheless, the t- and corresponding *p*-values are insignificant for all treatment effects. Note that the number of controls, i.e., matched cases from the group of people that (co-)owns solar installations and solely sells produced

energy, is rather small, with 13 to 16. As mentioned earlier, the small and unequal group size poses the question of statistical power. Resulting shortcomings shall be part of the discussion of the results. For now, note that in this analysis no differences in demand flexibility were found for (co-)owners of solar installations which consume as well as sell and solely sell, respectively, energy they produce from those facilities.

Table 11. Demand flexibility comparisons of Solar-consellers (treated) versus Solar-sellers controls) (source: authors' own calculations).

Dimension	Group	OBS	Mean	ATT	t-Value	p-Value
Usage of household appliances	Treated	47	4.118	0.479	0.604	0.274
	Controls	16	3.639			
Charging electrical appliances	Treated	47	3.125	−0.153	−0.218	0.414
	Controls	16	3.278			
Charging electrical means of transportation	Treated	47	3.714	0.214	0.297	0.384
	Controls	13	3.500			

H12. *Solar-sellers are more willing to be demand flexible than Solar-consumers.*

The last hypothesis H12 looks at possible differences between Solar-sellers (treated) and Solar-consumers (controls). The ATT for the usage of household appliances is the only positive manifestation in this case and amounts to 0.028 (Table 12). The ATT for the charging of other electrical appliances as well as the charging of electrical means of transportation show that Solar-sellers tend to be less flexible than Solar-consumers and amount to −0.267 and −0.161 in the same order. Regardless of the respective directions, all mean differences are statistically insignificant. Similar to the previous hypothesis, H11, the number of observations for the controls is rather low. The associated weaknesses must be considered when interpreting the results. In any case, H12 must be entirely rejected in the context of this study. No significant differences in reported demand flexibility were found between (co-)owners of solar facilities who solely sell or, on the other hand, solely consume produced energy.

Table 12. Demand flexibility comparisons of Solar-sellers (treated) versus Solar-consumers (controls) (source: authors' own calculations).

Dimension	Group	OBS	Mean	ATT	t-Value	p-Value
Usage of household appliances	Treated	43	3.800	0.028	0.057	0.477
	Controls	23	3.772			
Charging electrical appliances	Treated	43	3.300	−0.267	−0.461	0.323
	Controls	24	3.567			
Charging electrical means of transportation	Treated	43	3.706	−0.161	−0.249	0.402
	Controls	16	3.867			

Summary H7–H12

H7 to H12 look at the expressed willingness to behave in a demand flexible manner within the group of (co-)owners of solar installations and compares them according to the usage possibility of produced energy and additionally considers electricity consumers who are not involved with RE. Ultimately, significant differences were found in two cases. First, H8 showed that (co-)owners of solar installations who consume and sell produced energy at the same time are more willing to be demand flexible than people who are not involved with RE. This, however, is solely holds true for the usage of household appliances. Second, in H10, a significant difference between prosumers of solar facilities that have the choice between self-consumption and sale and those who can solely self-consume was found. Again, this difference does only hold for the usage of general

household appliances, such as a washing machine or a dishwasher. The applied matching technique caused small group sizes for H11 and H12, which has a destabilizing effect on the results that must be considered when interpreting the results.

5. Discussion

When discussing the results of our analysis, two aspects should be deepened: First, the empirical results should be critically reviewed by analyzing further insights from the wider research field (e.g., energy consumption behavior in households in general). Second, limitations from a methodological point of view must be discussed.

For the former, the influence of various factors such as economic factors, social norms, an individual's attitude towards environmental concern, and the institutional setting an individual consumers' energy has been highlighted in several studies. Accordingly, our general finding that co-owners show a different energy consumption behavior is in line with previous studies that align social mechanisms inherent to (co-)ownership business models in the energy sector as with (co-)owners' willingness to show more demand flexibility [7,30,38].

The reason for this is as follows: (Co-)investment usually leads to a deeper understanding of the issues related to the investment object. This improved awareness and knowledge is further reinforced in the context of energy infrastructures by the exchange with (co-)owners and consequently can serve as a catalyst for energy behavior change [63,64]; in the context of our study, the willingness to show flexible consumption behavior.

Regarding the behavioral differences between (co-)owners of different renewable energy technologies, the authors showed that the relationship between investment and involvement differs depending on the technology and that this difference also affects the willingness to engage in flexible consumption behavior. The (co-)owners of PV systems are usually located closer to the energy generation site and thus are likely show a greater involvement [65]. In contrast, the (co-)owners in our sample who invested in wind energy are likely to be located more distant from the turbine they have invested in than (co-)owners of PV installations. In these cases, (co-)ownership is likely to be perceived rather as a mere financial investment than an active means to participate in the energy sector [66]. Consequently, the impact of (co-)ownership on one's own behavior is lower and the willingness to behave flexibly is lower. However, a restriction is that the questionnaire did not explicitly ask about the spatial proximity so that the reasoning of this observation is a deductively derived conclusion that needs more empirical support.

Along the same line of argumentation is our interpretation of the observation that said relationship solely holds true for household appliances. This type of energy usage is an ubiquitous one that individual consumers will mostly understand with their relevant effects on energy consumption. Charging electrical appliances and, in particular, having a means of transportation in contrast is a preparatory stage and thus further away from the actual use, i.e., driving. With a more abstract relation to the actual use the planning of charging processes as part of becoming demand flexible thus require an extra cognitive effort. As various psychological factors are interlinked and play an important role for engagement [67] determining to a large extent whether an opportunity is seized or not the relation was expected to be stronger the closer it is to the actual use.

The observation of a significant difference between prosumers of solar facilities that have the choice between self-consumption and sale and those who can solely self-consume or are not involved with RE at all finally corroborates earlier findings [7] that only in the first case every kilowatt-hour not self-consumed becomes one potentially sold providing an intrinsic direct incentive for demand flexibility.

Regarding methodological aspects, this study is based on observational data from an online questionnaire. To contain the associated statistical biases, PSM was applied. The matching procedure is rooted in an homogenization of treatment and control groups based on observable characteristics that were part of the questionnaire. It is possible that

further, unobserved characteristics which are not part of the econometric modeling procedure, could have an influence on the calculated propensity scores and thus impact mean differences between treatment and control group. As this study considered all main demographic features it is unlikely that significant estimators are overlooked. Nevertheless, to enhance the explanatory power of matching models in this context further field research is required to find out whether other characteristics should be considered when matching the different types of RE owners.

Further, the matching approach and the subdivision into different owner types as well as energy usage possibilities cause unequal and partly small sample sizes. Both have potential to destabilize the calculation of the ATT [68,69]. However, the applied bootstrap allows for mean comparisons with small or unequal samples and therefore is a reliable method to control for this circumstance [70,71]. Hesterberg [70] demonstrated the potential to yield robust results with a total sample of 30 observations. Nevertheless, any comparisons involving people who (co-)own a biogas plant do not yield sound results. Further, if the data would allow it, a subdivision according to the usage possibilities for people who (co-)own a biogas plant, or a wind turbine could have interesting implications. It is necessary to conduct further research where those groups are approached more targeted to increase the sample size.

6. Conclusions

This paper investigated whether (co-)ownership of consumers in RE infrastructures has effects on their willingness to adapt their consumption behavior, i.e., to become demand-flexible and whether this effect differs across technologies (HA) and prosumption options (HB). Our analysis finds that HA is true: if consumers (co-)own a solar installation to produce RE they are generally more willing to show flexible energy consumption behavior. HB also holds true: when subdividing usage possibilities of produced RE within the group of people who (co-)own solar installations, only if both options, consumption and sale, are available a significant increase of the willingness to apply demand flexible behavior can be found. This distinction between the different scenarios (only auto-consumption/only sale/auto-consumption and sale) enables a more differentiated view allowing policy makers to tailor RE support measures.

In all cases, this only holds for household appliances. This is very likely due to the relationship between spatial proximity of (co-)owners to the infrastructure they own, the direct relationship to the actual use of the household appliance, and the resulting extent of involvement with energy related issues. This circumstance shows that generally the domain of household appliances solely, such as a washing machine or a dishwasher, is likely to be a viable option for demand flexibility approaches in a private context.

The results of our analysis are important in various ways. With a constantly rising share of RE in gross energy production, load management and grid stability become more and more important. Therefore, our findings can be used as a starting point for policy-makers to support flexible consumption behavior through promoting (co-)ownership.

In concrete terms, first, the pending transposition of the Renewable Energy Directive (RED II) and here the privilege of Renewable Energy Communities (RECs) to share electricity and other forms of energy between members or shareholders, even when using the public grid are directly relevant. Our findings indicate that in RECs involving photovoltaic installations, electricity sharing concepts can rely on the support of their members in terms of behavioral changes towards a flexible consumption regarding household appliance. Projects involving other RES behavioral factors are expected to be more difficult to exploit, demanding a rather technological approach. Therefore, national legislators should take into account this functional context of RES production and reward this type of behavior-related social and local benefit by targeted incentives in the enabling framework.

Second, and more generally, our results can contribute to mitigating rebound effects in RE projects. The rebound effect describes the paradox that increased efficiency goes

hand in hand with increased consumption. When applied to prosumership, increased savings from RE production lead the end user to the assumption that they are already saving enough energy/money, thus decreasing his/her willingness to adjust energy demand to production levels to save even more energy/money. This effect is exacerbated when one can only self-consume the produced energy, as storage may not be available or too expensive and sale to a third party is not an option, leading to a waste of excess production. Findings in the literature show that monetary gains such as potential bill savings often are not sufficient to promote flexible behavior and that other influences must also be addressed. This is in line with our observations stressing the importance of getting involved with one's consumption patterns, which is much more the case when consumer (co)-owners have the possibility to both, consume and sell the energy they produce, i.e., prosumership in the classical sense. Here, the relationship with spatial proximity to the RE installation and that with the direct use of electrical household appliances can indicate the direction both of future policy design and research projects. At the same time, our results prevent false expectations and will allow to calibrate support for energy efficiency programs and for RECs more targeted.

Abbreviations

ATT	Average Treatment Effect on the Treated
chi2	Chi square
Coef.	Coefficients
Conf.	Confidence
Cons	Constant
DSM	demand side management
EE	energy efficiency
H	Hypothesis
Max	Maximum value
Min	Minimum value
NGO	non-governmental organization
OBS	observations
Prob	probability
PSM	propensity score matching
PV	photovoltaic
R2	R square
RE	renewable energy
REC	Renewable Energy Communities
RED II	Renewable Energy Directive II

RES　　　renewable energy source
SCORE　Supporting Consumer Ownership in Renewable Energies
Std.Dev.　Standard Deviation
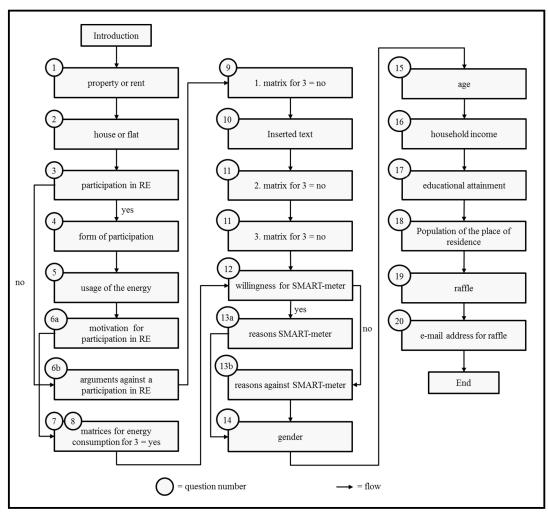vRES　　volatile renewable energy sources

Appendix A. Questionnaire Flow

Figure A1. Questionnaire flow participants had to go through.
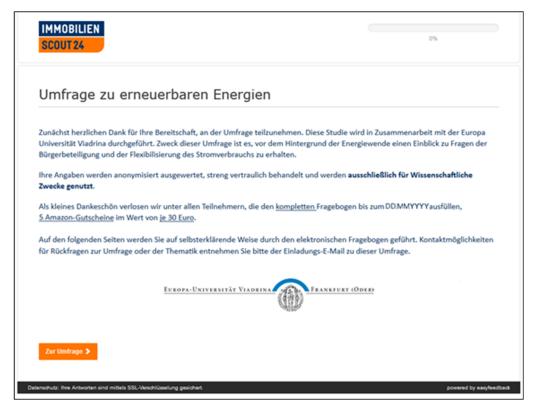
Appendix B. Questionnaire Screenshots and Translation

Figure A2. Screenshot of Questionnaire Page 1.

Renewable energy survey

First, thank you very much for your willingness to participate in the survey. This survey is conducted in cooperation with the European University Viadrina. The purpose of this survey is to gain insight into issues of citizen participation and the flexibilization of electricity consumption against the background of the energy transition.

Your data will be evaluated anonymously, treated as strictly confidential and will be used exclusively for scientific purposes.

As a small thank you, we will raffle 5 Amazon vouchers worth 30 Euros each among all participants who complete the entire questionnaire by the dd.mm.yyyy

On the following pages you will be guided through the electronic questionnaire in a self-explanatory way. Contact options for queries about the survey or the subject matter can be found in the invitation e-mail for this survey.

Figure A3. Screenshot of Questionnaire Page 2.

Where do you currently live?
Please select one single answer.
- Rental.
- In your own property.
- Other:

Figure A4. Screenshot of Questionnaire Page 3.

Do you currently live in a house or a flat?
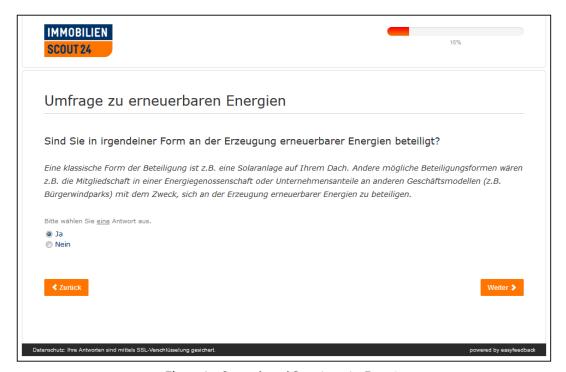Please select one single answer.

- In a House.
- In a flat.
- Other:

Figure A5. Screenshot of Questionnaire Page 4.

Do you participate in any way in the production of energy from renewable sources?

A classic form of participation is, for example, a solar installation on your roof. Other possible forms of participation would be, for example, membership in an energy cooperative or company shares in other business models (e.g., citizen wind farms) with the purpose of participating in the generation of renewable energies.

Please select one single answer.

- Yes.
- No.

Figure A6. Screenshot of Questionnaire Page 5.

In which way do you participate in the production of energy from renewable sources?

Please select one or more answers and fill in any missing information.

- I am (co-)owner of a solar power plant.
- I am (co-)owner of a wind turbine.
- I am (co-)owner of a biogas power plant
- I am (co-)owner of a: [user input]

Figure A7. Screenshot of Questionnaire Page 6.

How do you use the energy generated by your installation(s)?
Please select one single answer.

- Solely for own consumption
- Own consumption and sale of the generated energy
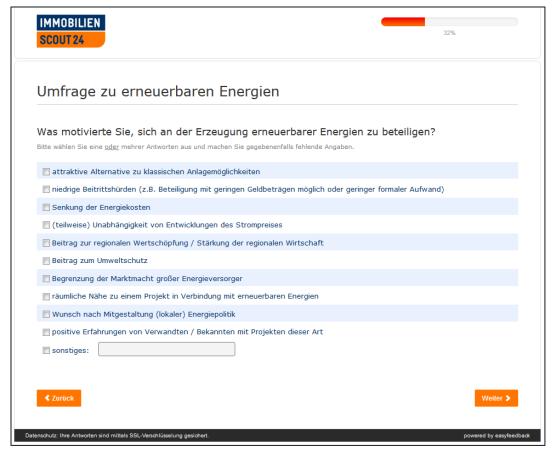- Solely sale of the generated energy (e.g., through a third party)

Figure A8. Screenshot of Questionnaire Page 7.

What motivated you to participate in renewable energy generation?
Please select one or more answers and fill in any missing information.

- Attractive alternative to classic investment opportunities
- Low entry barriers (e.g., participation with small amounts of money possible or low formal effort)
- Reduction of energy costs
- (Partial) independence from electricity price developments
- Contribution to regional value creation/strengthening of regional economy
- Contribution to environmental protection
- Limitation of the market power of large energy suppliers
- Spatial proximity to a project in connection with renewable energies
- Desire to participate in shaping (local) energy policy
- Positive experiences of relatives/acquaintances with projects of this kind
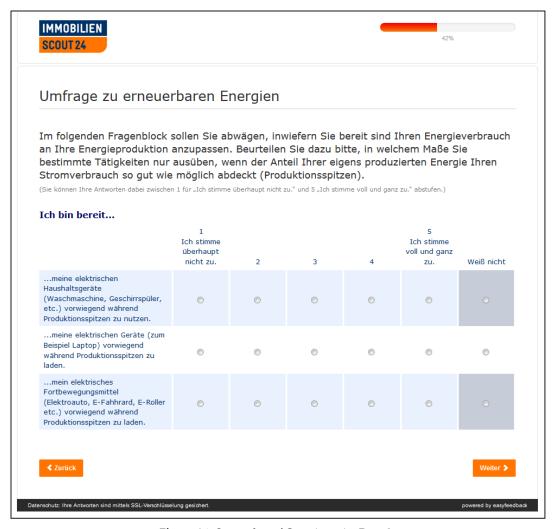- Other:

Figure A9. Screenshot of Questionnaire Page 8.

In the following block of questions, you are asked to consider to what extent you are willing to adapt your energy consumption to your energy production. For this purpose, please assess to what extent you would only perform certain activities when the share of your own produced energy covers your electricity consumption as much as possible (production peaks).

(You can grade your answers between 1 for "I do not agree at all" and 5 for "I agree completely". You can also choose "Do not know".)

I am willing to…

- … use household appliances (e.g., washing machine, dishwasher, etc.) mainly when the share of electricity from renewable sources in the grid is very high.
- … recharge electrical devices (e.g., laptop) mainly when the share of electricity from renewable sources in the grid is very high.
- … recharge electrical means of transportation (e.g., electric car/scooter/bike) mainly when the share of electricity from renewable sources in the grid is very high.
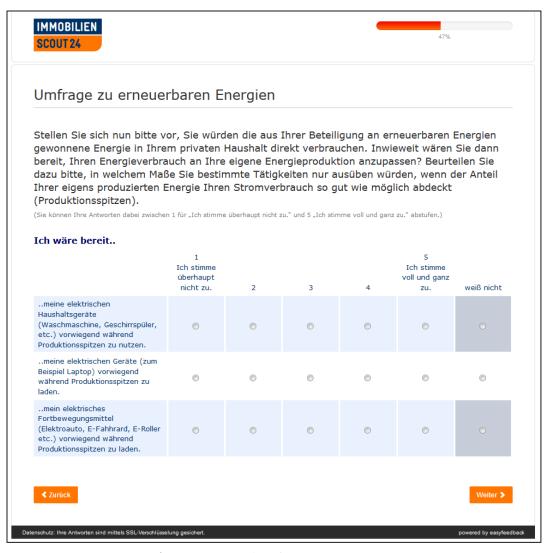
Figure A10. Screenshot of Questionnaire Page 9.

Now please imagine that you would directly consume the energy generated from your renewable energy participation in your private household.

To what extent would you then be willing to adapt your energy consumption to your own energy production?

Please assess to what extent you would only carry out certain activities if the share of your own produced energy covered your electricity consumption as much as possible (production peaks).

(You can grade your answers between 1 for "I do not agree at all" and 5 for "I agree completely". You can also choose "Do not know".)

I am willing to…

- … use household appliances (e.g., washing machine, dishwasher, etc.) mainly when the share of electricity from renewable sources in the grid is very high.
- … recharge electrical devices (e.g., laptop) mainly when the share of electricity from renewable sources in the grid is very high.
- … recharge electrical means of transportation (e.g., electric car/scooter/bike) mainly when the share of electricity from renewable sources in the grid is very high.
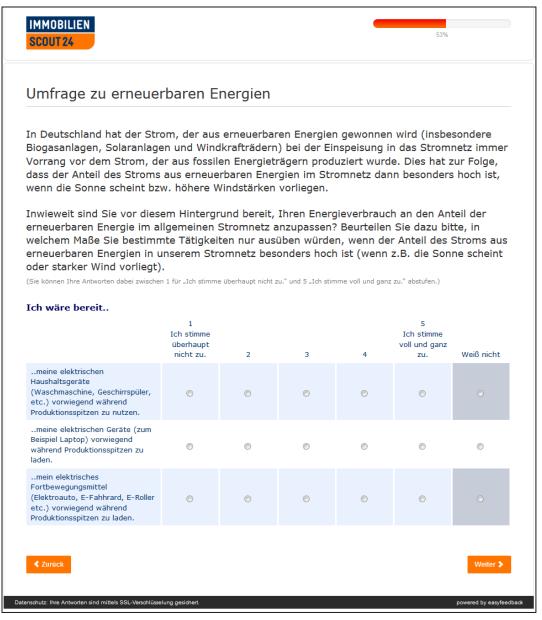
Figure A11. Screenshot of Questionnaire Page 10.

In Germany, electricity generated from renewable sources (especially biogas plants, solar panels, and wind turbines) always has priority over electricity produced from fossil fuels when it is fed into the grid. As a result, the share of electricity from renewable energies in the power grid is particularly high when the sun is shining or there are higher wind strengths.

Against this background, to what extent are you prepared to adjust your energy consumption to the share of renewable energy in the general power grid?

Please assess to what extent you would only carry out certain activities if the share of electricity from renewable energies in our power grid is particularly high (e.g., if the sun is shining or there is strong wind).

(You can grade your answers between 1 for "I do not agree at all" and 5 for "I agree completely". You can also choose "Do not know".)

I am willing to…

- … use household appliances (e.g., washing machine, dishwasher, etc.) mainly when the share of electricity from renewable sources in the grid is very high.
- … recharge electrical devices (e.g., laptop) mainly when the share of electricity from renewable sources in the grid is very high.
- … recharge electrical means of transportation (e.g., electric car/scooter/bike) mainly when the share of electricity from renewable sources in the grid is very high.
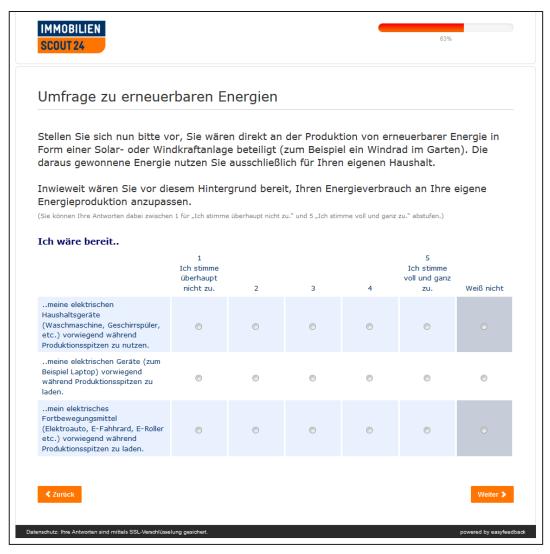

Figure A12. Screenshot of Questionnaire Page 11.

Now please imagine that you are directly involved in the production of renewable energy in the form of a solar or wind power plant (e.g., a wind turbine in your backyard). You use the energy generated from this exclusively for your own household.

Against this background, to what extent would you be willing to adapt your energy consumption to your own energy production?

(You can grade your answers between 1 for "I do not agree at all" and 5 for "I agree completely". You can also choose "Do not know".)

I am willing…

- …to use my household electrical appliances (washing machine, dishwasher, etc.) mainly during production peaks.
- …to charge my electrical devices (e.g., laptop) mainly during production peaks.

- …to charge my electronic means of transportation (electric car, e-bike, e-scooter etc.) mainly during production peaks.
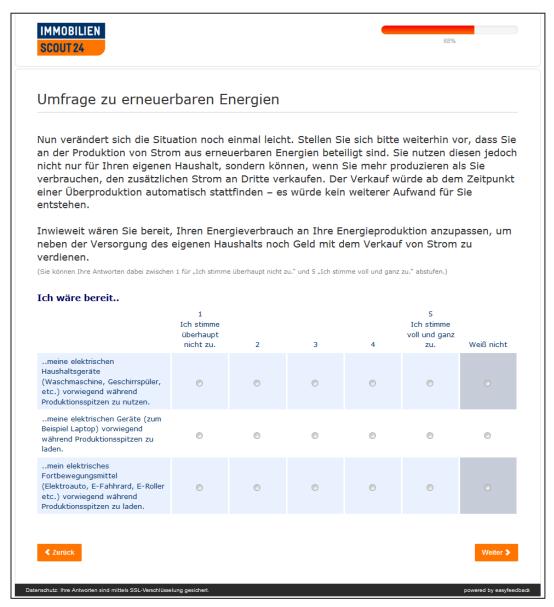

Figure A13. Screenshot of Questionnaire Page 12.

Now the situation changes slightly once again. Please continue to imagine that you are involved in the production of electricity from renewable sources. However, you not only use this for your own household, but if you produce more than you consume, you can sell the additional electricity to third parties. The sale would take place automatically from the moment of excess production. There would be no further effort on your part.

To what extent would you be willing to adjust your energy consumption to your energy production in order to earn money from selling electricity, in addition to supplying your own household?

(You can grade your answers between 1 for "I do not agree at all" and 5 for "I agree completely". You can also choose "Do not know".)

I am willing to…

- …use my household electrical appliances (washing machine, dishwasher, etc.) mainly during production peaks.
- …charge my electrical devices (e.g., laptop) mainly during production peaks
- …charge my electronic means of transportation (electric car, e-bike, e-scooter etc.) mainly during production peaks.

In order to efficiently manage the energy consumption of a private household, electricity providers offer the installation of a so-called "smart meter". This smart meter monitors your electricity consumption and is able to automatically adjust it to your consumption. Thus, it allows for an automated adjustment of your energy consumption to times when the share of renewable energies in the grid is particularly high.

Would you be willing to have such a smart meter installed in your household, even if it meant one-time financial expenses for you?

You can grade your answer between 1 for "I would never be prepared to do this" and 7 for "I would be prepared to do this in any case". You can also choose "Do not know".

Figure A14. Screenshot of Questionnaire Page 13.

What are the arguments against the use of technical instruments to make one's own usage behavior more flexible (e.g., a smart meter)?

Please select one <u>or</u> more answers and fill in any missing information.

- High (installation) costs
- Data protection concerns
- Insufficient coordination with other consumers/insufficient network infrastructure
- Insufficient information about the added value of smart meter deployment (e.g., cost savings, energy efficiency potential)
- I do not know
- Other:

Figure A15. Screenshot of Questionnaire Page 14.

What characteristics should technical instruments have to support you in making your electricity consumption more flexible (e.g., a smart meter)?

Please select one <u>or</u> more answers and fill in any missing information.

- Detailed display of consumption, amount of electricity produced and electricity costs
- Facilitation of billing processes (e.g., remote reading by suppliers)
- Flexibilization of billing schemes (e.g., monthly billing)
- Analysis of own consumption data/creation of a consumption profile
- (Anonymized comparisons with other users as benchmarking
- Possibility of automatic/remote controlled switching on of household appliances depending on production fluctuations (or in absence, e.g., during vacation time)
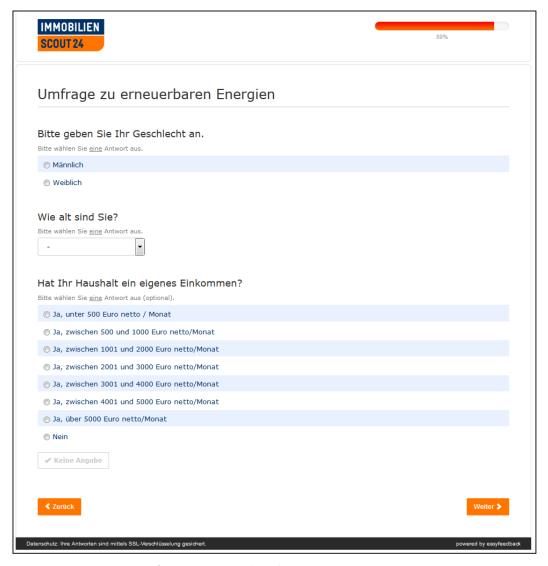- I do not know
- Other:

Figure A16. Screenshot of Questionnaire Page 15.

Please indicate your gender.
Please select one single answer.

- Male
- Female

How old are you?
Please select one single answer.
Does your household have its own income?
Please select one single answer (optional).

- Yes under 500 euro/month
- Yes between 500 and 1000 euro net/month
- Yes between 1001 and 2000 euro net/month
- Yes between 2001 and 3000 euro net/month
- Yes between 3001 and 4000 euro net/month
- Yes between 4001 and 5000 euro net/month
- Yes over 5000 euro net/month
- No
- Prefer not to say

Figure A17. Screenshot of Questionnaire Page 16.

What is your highest educational attainment?
Please select one single answer.
Prefer not to say
Approximately how many inhabitants does your place of residence have?
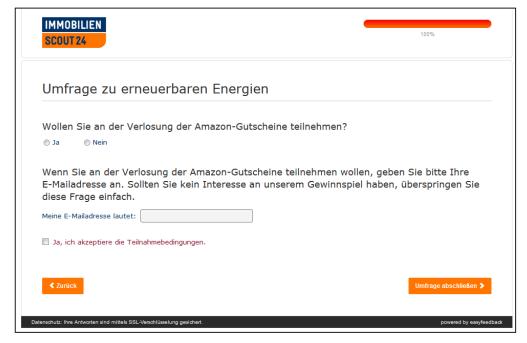Please select one single answer.
Do not know.

Figure A18. Screenshot of Questionnaire Page 17.

Do you want to participate in the raffle of Amazon vouchers?

Yes No

If you want to participate in the raffle of the Amazon vouchers, please enter your e-mail address. If you are not interested in our raffle, simply skip this question.

My e-mail address is:

Yes, I accept the conditions of participation.

Figure A19. Screenshot of Questionnaire Page 18.

Thank you for your participation!

You have successfully completed the survey.

You can close the browser window now.

Appendix C

Data Summary

Table A1. Depiction of summarized data used to produce results (source: authors' own calculations).

Variable	Obs	Mean	Std.Dev.	Min	Max
participation	2074	1.873	0.333	1	2
usage	264	1.693	0.823	1	3
group	2074	0.143	0.4	0	3
age	1978	4.616	1.416	1	7
income	1855	4.698	1.61	1	8
education	1934	3.56	1.472	1	6
population	1913	3.832	1.626	1	6
gender	1954	0.403	0.491	0	1
df_household	1994	3.483	1.391	1	5
df_electrical	2006	3.061	1.481	1	5
df_transport	1700	3.439	1.482	1	5
participation	2074	1.873	0.333	1	2

Codebook

Table A2. Depiction of variable names, labels and values for all variables used to produce the results.

Variable	Label	Values							
participation	(Co-) owner in RE	1 yes				2 no			
usage	Usage option for produced energy	1 solely self-consumption			2 consumption & sale			3 solely sale		
group	RE technology	0 Non-owner		1 Solar-owner		2 Wind-owner		3 Biogas-owner		
age	Age of participant	1 under 18	2 18–28	3 29–35	4 36–45	5 46–55	6 56–65	7 over 65	
income	Income of household	1 no income	2 under 500	3 500–1.000	4 1.001–2.000	5 2.001–3.000	6 3.001–4.000	7 4.001–5.000	8 more than 5.000
population	population of the city/village of the participant	1 1.000 or less	2 1.001–10.000		3 10.001–50.000		4 50.001–100.000	5 100.001–500.000	6 more than 500.000
gender	Gender of participant	0 male				1 female			
education	Educational achievement of participant	0 no official education	1 O-level	2 matriculation standard	3 apprenticeship	4 university of applied sciences degree	5 university degree	6 PhD	
df_household	Demand flexibility - Household appliances	1 strongly disagree		2 disagree	3 undecided		4 agree		5 strongly agree
df_electrical	Demand flexibility - electrical appliances	1 strongly disagree		2 disagree	3 undecided		4 agree		5 strongly agree
df_transport	Demand flexibility - means of transportation	1 strongly disagree		2 disagree	3 undecided		4 agree		5 strongly agree

Appendix D

Detailed data cleaning process

Table A3. Data cleaning process (source: authors' own calculations).

Generated Sample	2143
Participants with else option	−50
Cases with contradictory answers	−7
(co-)owners of more than one installation	−12
Remaining sample	2074

Logistic regression to select demographic variables for PSM—model

Logistic regression summary:

Number of obs = 1954
LR chi2(5) = 40.63
Prob > chi2 = 0.0000
Pseudo R2 = 0.0277
Log likelihood = −713.45679

Table A4. Logistic regression to determine matching variables (source: authors' own calculations).

Participation	Coef.	Std. Err	z-Value	*p*-Value	[95% Conf. Interval]	
gender	−0.3719166	0.1514672	−2.46	0.014	−0.6687869	−0.0750463
age	0.1806668	0.0652584	2.77	0.006	0.0527627	0.3085708
income	0.1312171	0.0581692	2.26	0.024	0.0172075	0.2452267
education	0.1018039	0.0646431	1.57	0.115	−0.0248943	0.2285022
population	−0.2589355	0.0633851	−4.09	0.000	−0.383168	−0.1347029
_cons	−1.851322	0.0873159	−21.20	0.000	−2.022459	−1.680186

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