The impact of (co-) ownership of renewable energy production facilities on demand flexibility

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Abstract:

The transition from fossil fuels to renewable energy sources requires financial, technical and social innovation. This is particularly true for wind and solar energy which have structural differences to fossils: they depend on weather and thus are volatile in their power production scheme. Not only must a new energy infrastructure be built, but consumers motivated to change consumption habits so as to balance demand with a volatile energy supply and to accept new technologies like smart meters.

Consumer (co-)ownership has proved successful in engaging consumers in financing renewable energy infrastructures, thus becoming "prosumers". Furthermore, research indicates that co-ownership can induce behavioral changes in energy consumption. Based on a sample of 2,143 completed questionnaires collected through an online survey, the study presented in this paper seeks to empirically prove this prediction and in particular whether (co-)ownership has an influence on demand side flexibility.

Our results show a statistical correlation between (co-)ownership of renewable energy production facilities and the willingness of private households to adjust their consumption behavior to match their electricity demand to production levels. However, the relation is complex: Only when prosumers have the choice between self-consumption and sale of the surplus electricity production to the grid we observe a statistically significant effect on consumption behavior. As every kilowatt-hour not consumed is one potentially sold to the grid an economic incentive kicks in which is equally important for energy efficient behavior. To exclude a self-selection bias we applied propensity score matching.

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1. Introduction

The transition from an energy system based on fossil fuels to a more sustainable system based on renewable energy sources is a global phenomenon. Governments in almost every country and supranational institutions such as the European Union have taken a variety of measures to increase renewable energy deployment, particularly in the domain of electricity production. Among other measures they have introduced mandatory targets to ensure a certain percentage of final energy consumption from renewable sources (e.g., Fischer and Geden 2014 for the countries of the European Union), investment incentives and soft loans (e.g. Agnolucci 2006; Abdmouleh et al. 2015), of feed-in tariffs (e.g., Shahmohammadi et al. 2015; Sun and Nie 2015), and auction mechanisms (e.g., Butler and Neuhoff 2008; Kitzing et al. 2012; Toke 2015) which have resulted in a significant share of renewable energy in the production and consumption of electricity, in particular in the countries of the European Union (e.g. Pacesila et al. 2016).

The progress of renewable energy deployment has brought several challenges with it. Balancing electricity supply and demand is of particular importance as the fluctuant nature of the two energy sources with the largest potential, i.e., wind and photovoltaic power require demand side management (DSM) in order to adapt consumption patterns to energy availability (e.g. Logenthiran et al. 2012; Verbong et al. 2013; Shariatzadeh et al. 2015). In order to realize more flexible consumption patterns and adapt demand to supply patterns, several strategies are tested in practice. However, most of these strategies have in common that they exclusively rely on a techno-centric perspective and therefore include an “inflexible” consumer figuration. Therefore, a need for more flexible conceptions of the electricity consumer by including a social perspective as well as more flexible relations between “the technical” and “the social” domain arises (Schick and Gad 2015).

This article ties to this aspect and investigates the influence of socio-economic drivers, in our case the role of (co-)ownership in renewable energy, in initiating energy flexibility behavior. Hence, it is in line with related recent research which analyses the effects of wider cultural and socio-economic forces on energy consumption behavior and the interaction of technical and social influences (e.g. Bell et al. 2015; Alberts et al. 2016; Rieger et al. 2016). The focus on the influence of energy (co-)ownership is derived from the characteristic that concepts engaging citizens to become (co-

)owners of renewable energy production facilities gained particular attention, particularly in developed countries (e.g., Lowitzsch and Goebel 2013; Yildiz 2014; Schreuer 2016; Vasileiadou et al. 2016). Thus, the aim of this article is to link (co-)ownership of renewable energy production facilities – and the incentives coming with it – to the willingness of consumers to adjust their consumption behavior and thus their electricity demand to production levels.

The paper is structured as follows. In section 2, a literature review provides a brief overview on research strands that are important for the further course of the paper. These include challenges that stem from the progressing deployment of renewable energy infrastructures, existing strategies for demand side management, citizen (co-) ownership in the renewable energy sector, and behavioral aspects that characterize (co-)owners of renewable energy facilities. Section 3 presents the hypotheses underlying the investigation which we tested with the help of a questionnaire. Section 4 describes in detail the used methodology, including aspects such as the data collection process, the econometric approach used for hypothesis testing as well as the model specifications. Section 5 presents and analyses the results of the questionnaire and the tested hypotheses. Finally, the paper ends with concluding remarks.

2. Literature review

There is substantial work that emphasizes the importance of changing consumer behavior in order to restructure the energy market in a sustainable way (e.g. Barbu et al., 2013; Laicane et al., 2015; Xenias et al. 2015). The continuing replacement of electricity from conventional power plants with electricity from renewable energy sources such as wind and solar energy has several implications with regard to the supply system stability. First, most renewable sources are characterized by highly fluctuating power generation which are not always predictable and consequently can have severe consequences for grid stability. Second, the ability to provide power balancing services in the classical sense disappears as the available power from renewable sources is often used entirely and thus cannot provide balancing ancillary service. These balancing challenges are further increased as renewable energy sources do not directly provide inertia to the grid in contrast to conventional power plants that normally are synchronous with the grid which supports the system frequency against changes. Hence, the promotion of flexible consumption patterns in the electricity markets is essential to compensate growth of fluctuating renewables and increase the system's ability to cope with the balancing and system stability issues that arise (Biegel et al. 2014).

Against this background, strategies to use predominantly technical innovations as a basis for a change in consumer behavior are in a particular focus. Among these strategies is the use of technical devices which provide real-time information so that consumers can vary their electricity consumption behavior according to the actual energy production (e.g., Nilsson et al. 2014; Zhao et al. 2015), technical equipment helping to schedule the usage of home appliances (Dlamini and Cromiers 2012, Lacain et al. 2015; Vardakas et al. 2015), the combined use of storage technologies and intelligent energy management systems which respond automatically to fluctuations in consumption (e.g. Becker et al. 2012; Römer et al. 2012; Erdinc et al. 2015), and the introduction of flexible electricity tariffs and real-time dynamic pricing schemes to steer consumer's behavior according to the grid system's needs and hereby address the challenge of balancing intermittent generation with demand fluctuation (e.g., Dütschke and Paetz 2013; Morales et al. 2014; Schreiber et al. 2015).

Starting from this techno-centric perspective, studies also elaborate approaches towards a general automation in order to realize system-compatible consumption patterns. However, the inevitable loss of freedom of the consumers can lead to a resistance against an automated energy management of their homes. Consequently, no matter in what way consumers are willing to adjust their electricity demand, it is vital for them to have the choice how they want to be demand flexible. Hence, this finding stresses the need of consumer willingness to face the future of energy consumption (Zipperer et al. 2013).

In the context of renewable energy deployment, (co-)ownership is discussed to be a suited tool to overcome barriers such as the lack of acceptance to changes. Particularly in developed countries, the expansion of renewable energy led to a diversity of implementation strategies ranging from decentralized regional solutions to large-scale centralized solutions (Engelken et al. 2016; Schmid et al. 2016). In this context, business models engaging citizens to become (co-)owners of (often) small scale, decentralized renewable energy production facilities gained particular popularity as characteristics such as social norms, trust and environmental concern can be effective. This, in turn, influences citizens' willingness to participate in and accept renewable energy production projects (e.g. Yildiz 2013; Dóci and Vasileiadou 2015; Kalkbrenner and Roosen 2016). In addition, previous work also indicates that the socio-economic setting of community-/ citizen-owned facility may affect the consumers' behavior in other ways (e.g., Yildiz et al. 2015; Rommel et al. 2016 for the analysis of consumers' willingness-to-pay). Hence, it is the aim of this paper to analyze whether the socio-economic setting also could have effects on consumption flexibility.

3. Hypotheses

From the previous theoretical insights, three main hypotheses are derived, with regard to consumers (co-)owning renewable energy production facilities. They refer to a comparison among people who are (co-)owners of renewable energy production facilities who use and/or sell their produced energy and people who do not have ownership stakes in renewable energy production facilities:

1. Consumers who (co-)own renewable energy production facilities and use the electricity they produce solely for their own consumption (hereinafter referred to as group 2) are more willing to adjust their electricity demand to production levels than people who do not (co-)own renewable energy production facilities (herein-after referred to as group 1).
2. Consumers who (co-)own renewable energy production facilities and use the electricity they produce for their own consumption as well as selling it to the grid (herein-after referred to as group 3)are more willing to adjust their electricity demand to production levels than people who do not (co-)own renewable energy production facilities (group 1).
3. Consumers who (co-)own renewable energy production facilities and use the electricity they produce for their own consumption as well as selling it (group 3) are more willing to adjust their electricity demand to production levels than people who (co-) own renewable energy production facilities and produce energy solely for their own consumption (group 2).

To exclude a self-selection bias in the answers referring to these three hypotheses we have applied propensity score matching (PSM), a statistical technique that uses observable characteristics of the sample, here the demographic part of our questionnaire to match the people from different groups before comparing their demand flexibility patterns.

Three additional hypotheses, with regard to non-owners, were tested using slightly less rigorous approach due to the hypothetical nature of the responses. The latter three hypotheses concern the potential change in behavior of people who do not (co-)own renewable energy production facilities when confronted with altered situations. To judge whether or not there is variation of the response patterns, the questions remain the same while the initial situations change. Hence, this is an analysis of hypothetical behavior and does not necessarily reflect actual patterns of behavior.

The fourth hypothesis compares the original response to demand flexibility (situation 1) with the answers of the participants when they were told to imagine that they (co-) own renewable energy production facilities and use the produced electricity for their own consumption (situation 2). Therefore the fourth hypothesis reads as follows:

4. People who are currently not (co-)owners of renewable energy production facilities would be more willing to adjust their electricity demand to production levels if the electricity they produce as (co-)owners of renewable energy production facilities were solely for their own consumption.

The initial situation in the fifth hypothesis stays the same (situation 1) whereas the circumstances of the participation in renewable energy production are enhanced by the possibility to not only consume but also to sell the produced energy (situation 3). Consequently the fifth hypothesis is quoted as follows:

5. People who are currently not (co-) owners of renewable energy production facilities would be more willing to adjust their electricity demand to production levels if the electricity they produce as (co-) owners of renewable energy production facilities were for their own consumption as well as for sale.

The sixth hypothesis simply compares the response patterns of situation 2 with situation 3 to find out if the enhancement of the possibility to consume as well as sell produced electricity has a positive impact on the willingness to be demand flexible.

6. People who are currently not (co-) owners of renewable energy production facilities would be more willing to adjust their electricity demand to production levels if the electricity they produce as (co-) owners of renewable energy production facilities were for their own consumption as well as for sale than if it were solely for their own consumption.

4. Methodical approach

The following chapter gives a short overview about the execution of the (4.1) data collection process, (4.2) the basic population, the generation of the sample and (4.3) the questionnaire. Sub-section 4.4 provides an overview of the econometric approach used for hypothesis testing as well as the model specifications.

4.1. Collection of the data

There is no publically accessible data base that could be used for this study. Thus, the formulated hypotheses require field research. The aim is to analyze if there is a statistically significant relation between (co-) ownership of renewable energy production facilities and the willingness to be demand flexible. The findings can be applied to the basic population by generating an adequate sample. This requires a broad data base. Consequently, a quantitative research in form of a questionnaire is more appropriate than a qualitative approach. A standardized questionnaire and easy operationalization facilitates the generation of an adequate sample (Burns et al. 2014).
The data was collected through an online survey hosted by ImmobilienScout24. The invitation for this online survey was sent via e-mail. Every field research has to meet certain quality criteria; namely objectivity, validity and reliability (Herrmann 2008). A comprehensive assessment of the methodical approach used in this study exceeds the scope of this paper. Therefore, the objectivity, validity and reliability of this approach have to be assumed in the given context.

4.2. Basic population and sample

The basic population consists of approximately 8 million users of www.immobilienscout24.de (Immobilien Scout GmbH 2015). To generate a representative image of the basic population it is necessary to draw a random sample (Mittag 2014). In this study, all characteristics are measured using a nominal scale. In association with a random sample a sufficient sample size can be expressed through:

$$n = \frac{z^2(pq)}{e^2} \qquad \text{(see Burns et al. 2014)}$$

n represents the size of the sample. *z* is the margin of safety and *e* the sampling error. *p* and *q* indicate the distribution within the interval or, in other words, the variation of the answers (ibid.).

The chosen level of confidence is 99 percent which equals a margin of safety of 2.58. The sampling error is ± 3 percent. The distribution within the interval is set at its maximum at 50 percent. That implies the following sample size:

$$n = \frac{2.58^2(50 * 50)}{3^2}$$

$$\underline{\underline{n = 1{,}849}}$$

In this case 1,849 datasets are necessary to apply the quantitative evidence to the basic population.

The first e-mail invitation was send to 58,879 ImmobilienScout24 users. The result was 986 completed questionnaires which meant the target of 1,849 datasets was not achieved. Consequently, 71,806 more e-mail invitations were sent out resulting in a final dataset of 2,143 complete questionnaires.

4.3. Questionnaire and method of measurement

This part focuses solely on the questions that are vital for answering the research questions. See Figure 1 for an overview of the flow of questions that the participants had to go through.

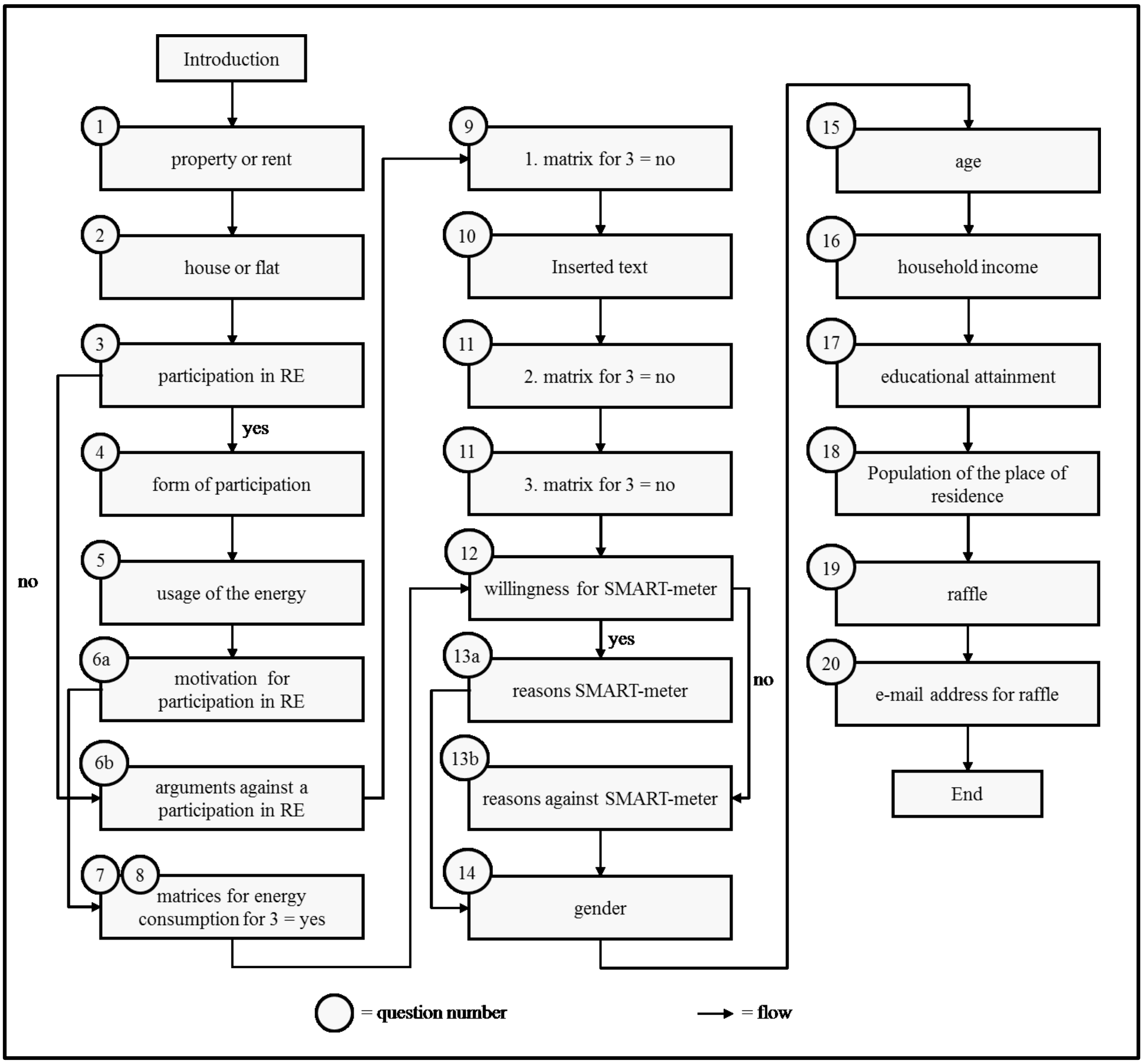

Figure 1: Flow of the online survey (source: authors' design).

The different groups that have to be formed in order to analyze the hypotheses were derived from the answers to question three and five (cf. Figure 1). Accordingly, those groups are:

1. People who (co-) own renewable energy production facilities and solely consume their produced energy.
2. People who (co-) own renewable energy production facilities and consume as well as sell their produced energy.
3. People who do not (co-) own renewable energy production facilities.

To express their willingness to be demand flexible, the participants were asked to rate three different statement on a scale from 1 for "I strongly disagree" to 5 for "I strongly agree". These statements represent varying dimensions of demand flexibility which are:

I am/ would be willing to…

1. …use household appliance (e.g. washing machine, dishwasher etc.) mainly when the share of electricity from renewable sources in the grid is very high.
2. …to recharge electrical devices (e.g. laptop) mainly when the share of electricity from renewable sources in the grid is very high.
3. …to 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.[5]

The participants also had the option to select the box "I do not know" thereby allowing them to opt for not giving an answer if they do not have an opinion – that would have distorted the results.

4.4 Estimation approach and the model specification

In order to analyze the statistical differences in demand flexibility among different types of owners, one has to control initial differences in characteristics between groups in order to avoid a potential bias in estimations. In order to do so, we use a matching technique. Matching can be applied in almost any policy evaluation context as long as there is a group of, in this case, households which are (co) owners of renewable energy production facilities and a group of households that do not own renewable energy production facilities which would serve as a suitable benchmark (or any combination among three groups under consideration as discussed further in this section). The ownership of renewable energy production facilities is considered as a treatment.[6] Matching relies on observed characteristics to construct a comparison group, assuming non-unobserved differences among groups.

In order to find a matching group one has to approximate all characteristics of the households from different groups as closely as possible. As the number of characteristics increases, the chance of finding a match drops significantly. This is known as the 'curse of dimensionality' and it increases exponentially with the increase of char-

[5] The questionnaire, originally, was in German, thus this is a translation that covers the sense of the initial questions.

[6] The term "treatment" derives from the medical sciences and has more meaning when is used in that context. However, this term means any differentiating characteristic that is as a result of certain policy or decision. This term is used throughout this paper in order to be in the same line with the dominant literature in this field.

acteristics against which you want to match the households. This can be avoided by using the propensity score matching – PSM (developed by Rosenbaum and Rubin, 1983). PSM is conditional probability that a household will be a part of one of the groups. In turn, PSM does not try to match the exactly the same values for all characteristics, instead, for each household (from different groups) it estimates a score that represents the likelihood of a household falling in the respective group. PSM reduces the dimensionality problem into one single score which is then used for matching.

We run the Propensity Scoring Algorithm, as the first step, using the following characteristic: gender, age, household income, level of education and size of the locality where the household is situated. Using STATA 13 **pscore** syntax we estimated the propensity score of the group of households that (co) own renewable energy production facilities and those that do not. In addition, it is also used to distinguish between group of households that (co) own renewable energy production facilities but use the electricity for different purposes.

Using three different specifications, one for each of the first three hypotheses, the generic matching model is as follows:

$$Treatment = \left(\frac{P_i}{1-P_i}\right) = \beta_0 + \beta_1 Gender + \beta_2 Age + \beta_3 NetIncome + \beta_4 Education + \beta_5 Location + \varepsilon_i$$

In specification *i*, corresponding to Hypothesis 1, the dependent variable takes the value of 1 if the household (co-) owns a renewable energy production facility and uses the energy they produce solely for their own consumption (i.e. belongs to Group 2) and 0 otherwise (i.e. belongs to Group 1).

In specification *ii*, corresponding to Hypothesis 2, the dependent variable takes the value of 1 if the household (co-) owns a renewable energy production facility and uses the energy they produce for their own consumption as well as for sale (i.e. belongs to Group 3) and 0 otherwise (i.e. belongs to Group 1).

In specification *iii*, corresponding to Hypothesis 2, the dependent variable takes the value of 1 if the household (co-) owns a renewable energy production facility and uses the energy they produce solely for their own consumption (i.e. belongs to Group 2) and 0 if the household owns renewable energy production facilities and uses the energy they produce for their own consumption as well as for sale (i.e. belongs to Group 2).

The independent variables in all specifications correspond to, the gender of the head of household (taking value of one if male and 0 otherwise); age of the head of household (expressed in years); disposable household income (expressed in annual income levels); level of education of the head of the household (expressed in terms of classifications, 1-0 level of education, 2-matriculation standard, 3-apprenticeship, 4-university of applied science degree, 5-university degree, 6-PhD); and location variable (expressed in terms of population in the city/village where the household is located).

Based on the propensity score, different parametric algorithms can be used to match the units from the treated and untreated group. In this case, we use nearest neighbor matching as a matching algorithm. As a robustness check, other matching algorithms were used (including radius matching and satisfaction matching). The results are consistent with those resulting from the nearest neighbor matching. Once we have evaluated the propensity score and found that there is a sufficient common support, we evaluated the Average Treatment Effect on the Treated (ATT), i.e. the effect that being in different groups has on various dimensions of demand flexibility.

5. Results and hypothesis testing

In all specifications, the diagnostic tests are valid showing that the propensity score matching yields estimates that are jointly significant. In addition, in all three specifications, the assumption of common support holds which is the precondition to apply the second step, i.e. calculate Average Treatment Effect on the Treated for each dimensions of the demand flexibility in all three specifications.

The matching technique as described in 4.4 was only applied in order to analyses the consistence of Hypotheses 1, 2 and 3. For Hypotheses 4 to 6 the top two boxes method is used which is a common way to assess rating scales (Tullis and Albert 2008). This method refers to the top boxes of the rating scale and classifies them as general agreement. In other words, if a participant chooses the 4 or the 5 on the rating scale (agree or strongly agree), the top two boxes are selected. To judge in this context, whether or not, observed tendencies are statistically significant a Chi² - test is executed.

5.1. Hypothesis 1

Hypothesis 1 compares the demand flexibility of people who are (co-)owners of renewable energy production facilities, who use the energy they produce solely for their own consumption (Group 2) with people who are not (co-)owners of renewable energy production facilities (Group 1).

The results (Table 1) indicate that the average treatment of the treated (ATT), i.e. the effect of (co-)ownership of renewable energy production facilities using the energy produced for own consumption, on demand flexibility is insignificant in all the dimensions of demand flexibility. The first hypothesis is therefore not supported. The results indicate that (co-)owners of renewable energy production facilities who use the energy they produce solely for their own consumption (Group 2), are not more likely to be demand flexible compared to Group 1 as hypothesis 1 predicts.

No.	Demand flexibility dimension	ATT (t values in brackets)
1.	Usage of household appliances	-0.016 (-0.211)
2.	Charging electrical appliances	-0.002 (-0.025)
3.	Charging electrical means of transportation	-0.013 (-0.171)

Table 1: Demand flexibility comparisons of Group 1 and Group 2 (source: authors' own calculations).

5.2. Hypothesis 2

Hypothesis 2 compares people who are (co-)owners of renewable energy production facilities, who use the energy they produce for their own consumption as well as for sale (Group 3) with people who are not (co-)owners of renewable energy production facilities (Group 1).

The results (table 2) indicate that ATT on demand flexibility is significant in all, but one dimension of the demand flexibility. The second hypothesis is therefore almost entirely supported. The results indicate that Group 3 is around 34 percent more demand flexible in terms of use of energy for household appliances compared to Group 1. Similarly, Group 3 is around 23 percent more demand flexible when it comes to the use of energy for charging electrical appliances compared to Group 1. The difference between Group 3 and Group 1 in demand flexibility in terms of use of energy for charging electrical means of transportation is statistically not significant.

No.	Demand flexibility dimension	ATT (t values in brackets)
1.	Usage of household appliances	0.337*** (3.180)
2.	Charging electrical appliances	0.226** (1.873)
3.	Charging electrical means of transportation	0.028 (0.265)

Table 2: Demand flexibility comparisons of Group 1 and Group 3 (source: authors' own calculations).

*Note: *'s denote significance levels (*** 1 percent; **5 percent)*

5.3. Hypothesis 3

Hypothesis 3 compares the demand flexibility of Group 2 and Group 3 as defined in the previous two Hypotheses. The results (table 3) indicate that ATT on demand flexibility is significant in all, but one dimension of the demand flexibility. The third hypothesis is therefore to a larger degree supported. The results indicate that Group 2 is around 27 percent less demand flexible in terms of use of energy for household appliances compared to Group 3. Similarly, Group 2 is almost 37 percent less likely to be demand flexible in terms of using the energy for charging electrical means of transport compared to Group 3. The difference between Group 3 and Group 2 in demand flexibility in terms of use of energy for charging electrical appliances is statistically not significant.

No.	Demand flexibility dimension	ATT (t values in brackets)
1.	Usage of household appliances	-0.272*** (-2.483)
2.	Charging electrical appliances	- 0.156 (-0.931)
3.	Charging electrical means of transportation	- 0.372*** (-2.436)

Table 3: Demand flexibility comparisons of Group 2 and Group 3 (source: Authors' own calculations).

*Note: *'s denote significance levels (*** 1 percent)*

5.4. Hypothesis 4

Hypothesis 4 is the first analysis of hypothetical behavior on the bases of different initial situations. People were asked to imagine that they are (co-)owners of renewable energy production facilities and use the energy they produce solely for their own consumption.[7] Thereby, the indicator of demand-flexibility in the hypothetical situation is continuously greater than in the initial situation (cf. figure 2). The first time the slope with the usage of household appliances from 53.4 to 69.7 percent is not the largest. The largest gap at 17.2 percentage points can be observed with regard to the charging of other electrical appliances. The question on recharging of electrical means of transportation is the smallest – with a difference of 16.2 percentage points – but still very close to the usage of household appliances.

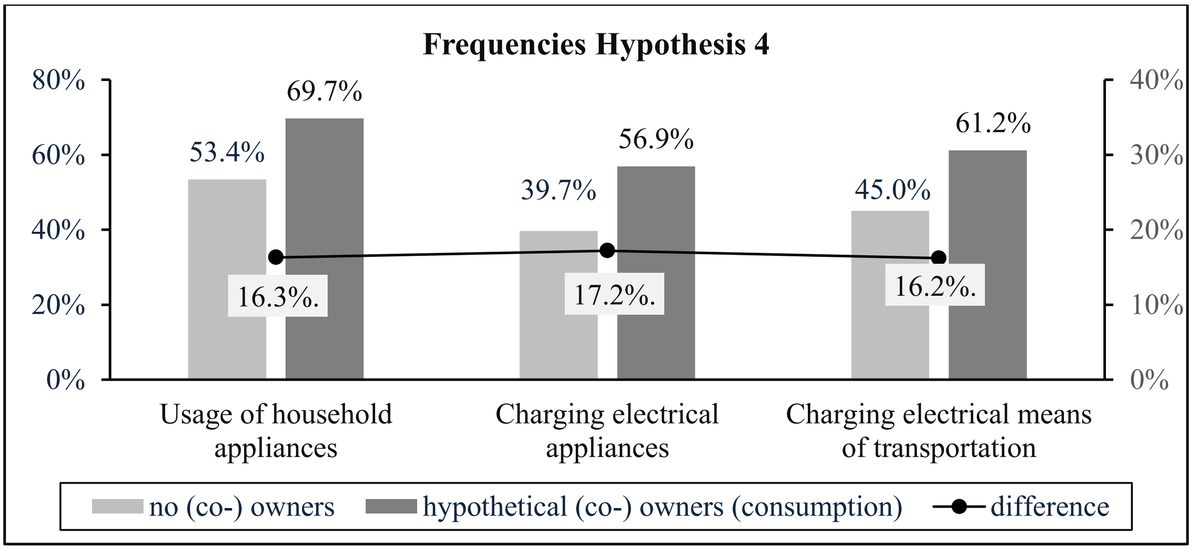

Figure 2: Results for hypothesis 4 - Top two boxes on a 5 level rating-scale (source: Authors' design).

With a p value of 0.00, all differences of the compared answers are statistically highly significant. Consequently, hypothesis 4 is temporarily confirmed to the full extent. People who are currently not (co-)owners of renewable energy production facilities would be more willing to adjust their electricity demand to production levels if the

[7] "People who are currently not (co-) owners of RE production facilities would be willing to adjust their electricity demand to production levels if the electricity they produce as (co-) owners of RE production facilities were solely for their own consumption."

electricity they produce as (co-)owners of renewable energy production facilities were solely for their own consumption.

5.5. Hypothesis 5

In order to analyze hypothesis 5, the participants were asked to imagine that they are (co-)owners of renewable energy production facilities and the can not only consume but also sell the energy they produce.[8] Surprisingly, the results are not as good as they would be if the people produce energy solely for consumption. The difference at the usage of household appliances amounts to 13.4 percent points. Moreover, the recharging of electrical appliances varies by about 15.7 percent points. The willingness to flexibly recharge electrical means of transportation increased from 45 percent to 58.9 percent.

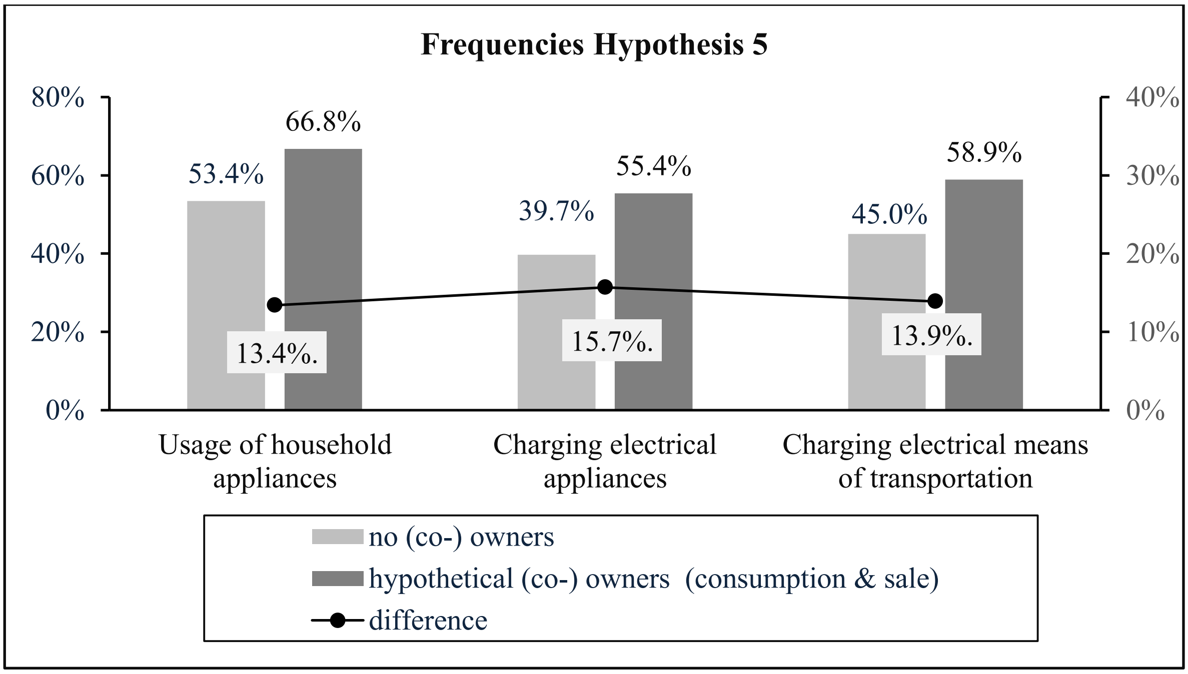

Figure 3: Results for hypothesis 5 - Top two boxes on a 5 level rating-scale (source: authors' design).

All described tendencies are statistically significant ($p = 0.00$). Thus, hypotheses 5 can be regarded as temporarily confirmed. People who are currently not (co-)owners of renewable energy production facilities would be willing to adjust their electricity

[8] "People who are currently not (co-) owners of RE production facilities would be willing to adjust their electricity demand to production levels if the electricity they pro-duce as (co-) owners of RE production facilities were for their own consumption as well as for sale."

demand to production levels if the electricity they produce as (co-)owners of renewable energy production facilities were for their own consumption as well as for sale.

5.6. Hypothesis 6

For the final hypothesis, the answers of the hypothetical (co-)owners of renewable energy production facilities are compared with respect to the possibility to not only consume but also sell the energy they produce.[9] The observable differences are minor, even though they reveal a clear tendency. The participants show a slight but constant increase in willingness to be demand flexible if they solely consume the energy they produce (cf. figure 4). The biggest gap, at 2.9 percentage points, can be observed in the category "Usage of household appliances" followed by "Charging of electrical means of transportation" at 2.3 percentage points. The recharging process of other electrical appliance shows a difference of 1.5 percent points.

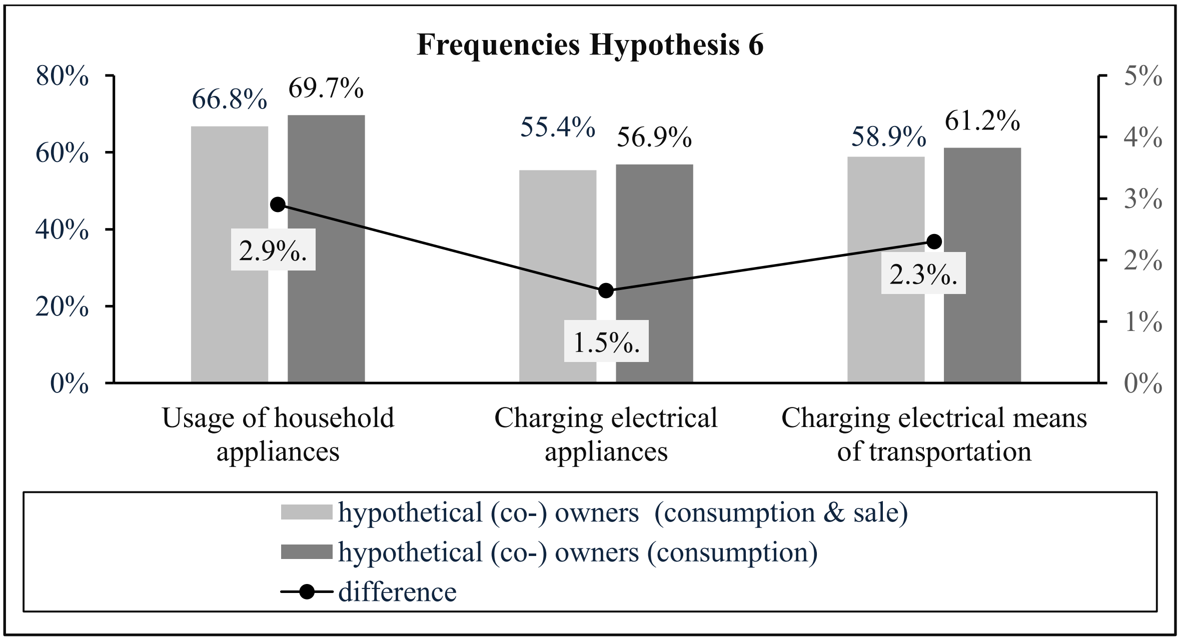

Figure 4: Results for hypothesis 6 - Top two boxes on a 5 level rating-scale (source: authors' design).

Even if the described tendencies are contrary to hypothesis 6 neither of the differences is statistically significant – not even close to that (cf. figure 5). However, hypothesis 6 has to be temporarily rejected. People who are currently not (co-) owners of renewable energy production facilities are not more willing to adjust their electricity

[9] "People who are currently not (co-) owners of RE production facilities would be more willing to adjust their electricity demand to production levels if the electricity they produce as (co-) owners of RE production facilities were for their own consumption as well as for sale than if it were solely for their own consumption."

demand to production levels if the electricity they produce as (co-) owners of renewable energy production facilities were for their own consumption as well as for sale than if it were solely for their own consumption.

Dimension	Difference	Asymptotic Significance (p)
Usage of household appliances	+2.9%.	0.887
Charging electrical appliances	+1.5%.	0.270
Charging electrical means of transportation	+2.3%.	0.356

Figure 5: Significance test for hypothesis 6[10] (source: authors' design).

5.7. Summary and interpretation of the statistical evaluation

The previous deliberations show that a statistical correlation between consumer (co-) ownership of renewable energy production facilities and the willingness to adjust the electricity demand to production levels can be asserted solely under specific circumstances. According to the results at hand, the end-user is not generally demand-flexible – even if he produces his own energy. It was not possible to prove a difference in consumption behavior between people who produce and (solely) consume their own energy and people who only consume energy (H1).

In the context of this study only one constellation had an influence on the willingness to be demand-flexible: if the end-user being a prosumer has the possibility to consume as well as to sell the energy he produced, he is more willing to align the usage of household appliances with production levels. The statistical difference that justifies this conclusion holds true for the comparison between people who consume and sell their own energy with people who only produce (H3), or people who only consume energy (H2). However, the same constellation does not lead to increased willingness to refrain from recharging other electrical appliances or means of transportation when energy production levels are low. This leads to the conclusion that a flexible usage of household appliances is the only real leverage for an applicable DSM approach in a private environment.

[10] As the available cases for hypothesis 6 do not meet the requirements for a Chi^2-test ($n^* > 5$), the asymptotic significance is calculated with a Wilcoxon signed-rank test

The evaluation of H4, H5 and H6 provide a very different picture. The results from H4 and H5 imply that both consumption, and consumption combined with the sale of produced energy, has a positive impact on the willingness to apply DSM methods. Additionally, all dimensions of demand flexibility under H4 and H5 show highly significant differences to the initial situation, whereas only the usage of household appliances yielded significant results in connection with H1, H2 and H3. In contrast to the evaluation of H3, the simple consumption of the energy has a marginally better effect than the combination of consumption and sale (H6). However, this difference is statistically not significant and therefore should be neglected.

When comparing the findings from the real-life situation (H1, H2 and H3) with the hypothetical situations (H4, H5, and H6), two crucial questions remain to be answered. First, why do people who currently not (co-)own renewable energy production facilities impute a comparably low value to the possibility of additionally selling the excess production to the grid? Different explanations are possible. It stands to reason that people, who are currently not involved with private renewable energy production, are not familiar with mechanisms that automatically sell overproduced energy. This might be a sign of fear or distrust regarding complex energy technology. This assertion could also explain the good results of demand-flexibility in connection with simple consumption of self-produced energy; the concept of producing and consuming energy is much easier to imagine, or to understand respectively, than the more complex system of self-production, consumption and additional sale. Another obvious reason could be that people, who are not yet involved with renewable energy production, are not aware of the added value potential of selling self-produced energy. Many people do not know how expensive electricity is, how much they pay for their own consumption (PricewaterhouseCoopers 2015), and, consequently, how much they could earn with the sale of energy.

The second essential question is: which of the findings in this study will likely be of greater value for further research? One the one hand, this study looked at real life situations in H1, H2 and H3: people have to have the possibility to consume as well as sell their energy in order to be willing to apply DSM methods. On the other hand, the results of the hypothetical H4, H5 and H6: here, people show the same willingness to apply DSM methods whether they only consume, or consume as well as sell the energy they produce. As described earlier, the results of the last three hypotheses are an outcome of hypothetical questions (cf. section3). The value of results as an outcome of hypothetical questions is widely disputed in modern market research and consequently such questions should be avoided if possible (Koch 2012). Hence, the results from the non-hypothetical questions (H1, H2 an H3) are of greater value in order to evaluate the validity of the analyzed hypotheses and should be the basis for further interpretation and research approaches.

6. Conclusion

The aim of this paper was to analyze whether the setting of being a (co-)owner of a renewable energy facility has effects on consumption flexibility. The results of the econometric analysis of the questionnaire showed the following: In all specifications, the diagnostic tests are valid and the results suggest that (co-)ownership of renewable energy production facilities has an impact on demand flexibility only in specific cases and for specific dimensions of demand flexibility. Above all, in cases when the end-users as prosumers have the possibility to consume as well as to sell the produced energy, they are inclined to be more demand flexible.

Facing the current developments on the energy market, i.e., the rising importance of renewable energy often accompanied by decentralized energy production and grids, a growing importance of demand side management is inevitable. Hence, the central results of this study should be further investigated and enriched. In this regard, a first approach could be to analyze why (co-)owners of renewable energy production facilities who only consume their energy show a limited motivation to adjust their energy consumption to production levels. Probably, that could be associated with a variant of the rebound effect. The rebound effect generally describes the paradox that increased efficiency goes hand in hand with an increased consumption (Barbu et al. 2013). When applied to this case, the rebound effect could be described the following way: increased savings from renewable energy production (increased efficiency from a cost perspective) lead the end-user to the assumption that he is already saving enough energy/money thus decreasing his willingness to adjust his energy demand to production levels in order to save even more energy/ money.

Other approaches to the topic of (co-)ownership and demand response would incorporate research on policy aspects. As described in the introduction and in the literature review section, business models to engage citizens as (co-)owners play an important role in the context of renewable energy deployment, particularly in developed countries. Hence, the finding of this paper that consumption flexibility could be fostered through providing prosumers with the possibility both, to consume as well as to sell the produced energy is an important starting point for further demand side management measures. However, the regulatory framework for prosumer schemes is not very favorable. Several countries have already for several years or recently introduced (e.g., Germany) auction mechanisms that rather favor large-scale utilities and big companies instead of small-scale decentralized facilities and small actor groups (e.g. del Río and Linares 2014; Klessmann et al. 2015). Consequently, it would be worthwhile to re-think existing regulations as (co-)ownership might be an important determining factor to enhance consumer flexibility. In addition, approaches to use “soft” tools in environmental and energy policy or mixed strategies that combine different policy instruments could also be a way to deepen the presented analysis and insights on factors that foster consumption flexibility (Michalek et al. 2015).

Literature

Abdmouleh, Z., Alammari, R. A., & Gastli, A. (2015). Recommendations on renewable energy policies for the GCC countries. Renewable and Sustainable Energy Reviews, 50, 1181-1191.

Agnolucci, P. (2006). Use of economic instruments in the German renewable electricity policy. Energy Policy, 34(18), 3538-3548.

Alberts, G., Gurguc, Z., Koutroumpis, P., Martin, R., Muûls, M., & Napp, T. (2016). Competition and norms: A self-defeating combination?. Energy Policy, 96, 504-523.

Barbu, A., Griffiths, N., & Morton, G. (2013). Achieving energy efficiency through behaviour change: what does it take? European Environment Agency (EEA), Copenhagen, 2013. URL: http://www.eea.europa.eu/publications/achieving-energy-efficiency-through-behaviour.

Becker, B., Kellerer, A., & Schmeck, H. (2012). User interaction interface for energy management in smart homes. Conference Publications – 2012 IEEE PES Innovative Smart Grid Technologies (ISGT). DOI: 10.1109/ISGT.2012.6175616.

Bell, S., Judson, E., Bulkeley, H., Powells, G., Capova, K. A., & Lynch, D. (2015). Sociality and electricity in the United Kingdom: The influence of household dynamics on everyday consumption. Energy Research & Social Science, 9, 98-106.

Biegel, B., Hansen, L. H., Stoustrup, J., Andersen, P., & Harbo, S. (2014). Value of flexible consumption in the electricity markets. Energy, 66, 354-362.

Burns, A. C., Bush, R. F., & Sinha, N. (2014). Marketing Research. 7th edition, Pearson Education, Boston, Ma., 2014.

Butler, L., & Neuhoff, K. (2008). Comparison of feed-in tariff, quota and auction mechanisms to support wind power development. Renewable Energy, 33(8), 1854-1867.

del Río, P., & Linares, P. (2014). Back to the future? Rethinking auctions for renewable electricity support. Renewable and Sustainable Energy Reviews, 35, 42-56.

Dlamini, N. G., & Cromieres, F. (2012). Implementing peak load reduction algorithms for household electrical appliances. Energy Policy, 44, 280-290.

Dóci, G., & Vasileiadou, E. (2015). “Let׳ s do it ourselves” Individual motivations for investing in renewables at community level. Renewable and Sustainable Energy Reviews, 49, 41-50.

Dütschke, E., & Paetz, A. G. (2013). Dynamic electricity pricing—Which programs do consumers prefer?. Energy Policy, 59, 226-234.

Engelken, M., Römer, B., Drescher, M., Welpe, I. M., & Picot, A. (2016). Comparing drivers, barriers, and opportunities of business models for renewable energies: A review. Renewable and Sustainable Energy Reviews, 60, 795-809.

Erdinc, O., Paterakis, N. G., Pappi, I. N., Bakirtzis, A. G., & Catalão, J. P. (2015). A new perspective for sizing of distributed generation and energy storage for smart households under demand response. Applied Energy, 143, 26-37.

Fischer, S., & Geden, O. (2014). Moving targets: negotiations on the EU’s energy and climate policy objectives for the post-2020 period and implications for the German energy transition. SWP Research Paper 3/2014, Stiftung Wissenschaft und Politik (SWP) Berlin 2014. URL: http://nbn-resolving.de/urn:nbn:de:0168-ssoar-385585

Immobilien Scout GmbH Unternehmen (2015). Available at http://www.immobilienscout24.de/unternehmen/immobilienscout24.html.

Kalkbrenner, B. J., & Roosen, J. (2016). Citizens’ willingness to participate in local renewable energy projects: The role of community and trust in Germany. Energy Research & Social Science, 13, 60-70.

Kitzing, L., Mitchell, C., & Morthorst, P. E. (2012). Renewable energy policies in Europe: Converging or diverging?. Energy Policy, 51, 192-201.

Klessmann, C., Wigand, F., Tiedemann, S., Gephart, M., Maurer, C., Tersteegen, B., Ragwitz, M., Höfling, H., Winkler, J., Kelm, T., Jachmann, H., Ehrhart, K., Haufe, M., Kohls, M., Linnemeyer, M., Meitz, C., Riese, C. and Nebel, J.A. (2015). Ausschreibungen für erneuerbare Energien: Wissenschaftliche Empfehlungen. Ecofys, Bundesministerium für Wirtschaft und Energie (BMWi), Berlin, Germany.

Koch, J. (2012). Marktforschung: Grundlagen und praktische Anwendungen. 6th edition, Oldenbourg, München, 2012.

Laicane, I., Blumberga, D., Blumberga, A., & Rosa, M. (2015). Reducing household electricity consumption through demand side management: the role of home appliance scheduling and peak load reduction. Energy Procedia, 72, 222-229.

Logenthiran, T., Srinivasan, D., & Shun, T. Z. (2012). Demand side management in smart grid using heuristic optimization. IEEE Transactions on Smart Grid, 3(3), 1244-1252.

Lowitzsch, J., Goebel, K. (2013). Vom Verbraucher zum Energieproduzenten. Finanzierung dezentraler Energieproduktion unter Beteiligung von Bürgern als Konsumenten mittels Consumer Stock Ownership Plans (CSOPs). Zeitschrift für Neues Energierecht (ZNER), 17(3), 237-244.

Michalek, G., Meran, G., Schwarze, R., & Yildiz, Ö. (2015). Nudging as a new 'soft' tool in environmental policy. An analysis based on insights from cognitive and social psychology. Discussion Paper recap15 No. 20, October 2015, Viadrina University Frankfurt/O., Germany. URL: https://www.europa-uni.de/de/forschung/institut/recap15/downloads/recap15_DP021.pdf.

Morales, J. M., Conejo, A. J., Madsen, H., Pinson, P., & Zugno, M. (2014). Facilitating Renewable Integration by Demand Response Demand response. In: Morales, J. M., Conejo, A. J., Madsen, H., Pinson, P., & Zugno, M. [Eds.]: Integrating renewables in electricity markets: Operational problems. Springer Science & Business Media, New York, NY, 2014, pp. 289-329.

Nilsson, A., Bergstad, C. J., Thuvander, L., Andersson, D., Andersson, K., & Meiling, P. (2014). Effects of continuous feedback on households' electricity consumption: Potentials and barriers. Applied Energy, 122, 17-23.

Pacesila, M., Burcea, S. G., & Colesca, S. E. (2016). Analysis of renewable energies in European Union. Renewable and Sustainable Energy Reviews, 56, 156-170.

PricewaterhouseCooper (2015). Was zahlen Sie für Ihren Strom?: Verbraucher, die nicht wissen wie viel sie im Monat für ihren Stromverbrauch zahlen. URL: http://strom-report.de/strompreise/.

Rieger, A., Thummert, R., Fridgen, G., Kahlen, M., & Ketter, W. (2016). Estimating the benefits of cooperation in a residential microgrid: A data-driven approach. Applied Energy, 180, 130-141.

Rommel, J., Sagebiel, J., & Müller, J. R. (2016). Quality uncertainty and the market for renewable energy: Evidence from German consumers. Renewable Energy, 94, 106-113.

Rosenbaum, P. & Rubin, D. (1983). The Central Role of the Propensity Score in Observational Studies for Causal Effects. Biometrika, 70, 41–55

Römer, B., Reichhart, P., Kranz, J., & Picot, A. (2012). The role of smart metering and decentralized electricity storage for smart grids: The importance of positive externalities. Energy Policy, 50, 486-495.

Schick, L., & Gad, C. (2015). Flexible and inflexible energy engagements—A study of the Danish Smart Grid Strategy. Energy Research & Social Science, 9, 51-59.

Schmid, E., Knopf, B., & Pechan, A. (2016). Putting an energy system transformation into practice: The case of the German Energiewende. Energy Research & Social Science, 11, 263-275.

Schreiber, M., Wainstein, M. E., Hochloff, P., & Dargaville, R. (2015). Flexible electricity tariffs: Power and energy price signals designed for a smarter grid. Energy, 93, 2568-2581.

Schreuer, A. (2016). The establishment of citizen power plants in Austria: A process of empowerment?. Energy Research & Social Science, 13, 126-135.

Shahmohammadi, M. S., Yusuff, R. M., Keyhanian, S., & Shakouri, H. (2015). A decision support system for evaluating effects of Feed-in Tariff mechanism: Dynamic modeling of Malaysia's electricity generation mix. Applied Energy, 146, 217-229.

Shariatzadeh, F., Mandal, P., & Srivastava, A. K. (2015). Demand response for sustainable energy systems: A review, application and implementation strategy. Renewable and Sustainable Energy Reviews, 45, 343-350.

Sun, P., & Nie, P. Y. (2015). A comparative study of feed-in tariff and renewable portfolio standard policy in renewable energy industry. Renewable Energy, 74, 255-262.

Toke, D. (2015). Renewable Energy Auctions and Tenders: How good are they?. International Journal of Sustainable Energy Planning and Management, 8, 43-56.

Tullis, T., & Albert, W. (2013). Measuring the User Experience: Collecting, Analyzing, and Presenting Usability Metrics. 1st edition, Morgan Kaufmann, Waltham, MA., 2008.

Vardakas, J. S., Zorba, N., & Verikoukis, C. V. (2015). Performance evaluation of power demand scheduling scenarios in a smart grid environment. Applied Energy, 142, 164-178.

Vasileiadou, E., Huijben, J. C. C. M., & Raven, R. P. J. M. (2016). Three is a crowd? Exploring the potential of crowdfunding for renewable energy in the Netherlands. Journal of Cleaner Production, 128, 142-155.

Verbong, G. P., Beemsterboer, S., & Sengers, F. (2013). Smart grids or smart users? Involving users in developing a low carbon electricity economy. Energy Policy, 52, 117-125.

Xenias, D., Axon, C. J., Whitmarsh, L., Connor, P. M., Balta-Ozkan, N., & Spence, A. (2015). UK smart grid development: An expert assessment of the benefits, pitfalls and functions. Renewable Energy, 81, 89-102.

Yildiz, Ö. (2013). Energiegenossenschaften in Deutschland–Bestandsentwicklung und institutionenökonomische Analyse. Zeitschrift für das gesamte Genossenschaftswesen, 63(3), 173-186.

Yildiz, Ö. (2014). Financing renewable energy infrastructures via financial citizen participation–The case of Germany. Renewable Energy, 68, 677-685.

Yildiz, Ö., Rommel, J., Debor, S., Holstenkamp, L., Mey, F., Müller, J. R., Radtke, J., & Rognli, J. (2015). Renewable energy cooperatives as gatekeepers or facilitators? Recent developments in Germany and a multidisciplinary research agenda. Energy Research & Social Science, 6, 59-73.

Zhao, B., Xue, M., Zhang, X., Wang, C., & Zhao, J. (2015). An MAS based energy management system for a stand-alone microgrid at high altitude. Applied Energy, 143, 251-261.

Zipperer, A., Aloise-Young, P. A., Suryanarayanan, S., Roche, R., Earle, L., Christensen, D., Bauleo, P. & Zimmerle, D. (2013). Electric energy management in the smart home: Perspectives on enabling technologies and consumer behavior. Proceedings of the IEEE, 101(11), 2397-2408.