Energy Policy 87 (2015) 562–572

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Willingness to pay lip service? Applying a neuroscience-based method to WTP for green electricity

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HIGHLIGHTS

- We introduce a neuroscience-based method for studying consumer WTP for green energy.
- WTP derived from Neuropricing is above self-reported WTP for green energy.
- Neuropricing allows smaller samples and eliminates respondents' strategic behavior.
- Neuropricing offers a powerful new resource for companies marketing green energy.
- Neuropricing offers new perspectives for architects of energy policy.

ARTICLE INFO

Article history:
Received 13 June 2015
Received in revised form
30 September 2015
Accepted 1 October 2015

Keywords:
Renewable energy
Green energy
Green electricity
Marketing
Willingness-to-pay
Neuroscience

ABSTRACT

Consumers' willingness to pay (WTP) represents a central question for providers of renewable energy. Most studies on the subject have used contingent valuation and choice experiments. However, all empirical designs employed to date suffer from serious biases, such as strategic behavior. We introduce a novel neuroscience-based approach to renewable energy-related WTP research, Neuropricing, which eliminates some of these biases. We tested consumers' WTP for two different green electricity products and found WTP for these products to be about 15% above that for a non-green electricity tariff. Our results suggest that Neuropricing is indeed able to eliminate strategic behavior. Moreover, this approach allows for WTP studies with much smaller sample sizes than traditional methods require. The neuroscience methodology can be used by researchers and marketers alike not only for testing the effects of product attributes on WTP but also for evaluating WTP effects of specific messages in marketing communications. Thus it may lead to a better understanding of consumer behavior and hence facilitate more successful marketing of renewable energy.

1. Introduction

Climate change poses a serious threat to contemporary humanity. As the burning of fossil fuels is the prime causative factor in climate change, renewable energy technologies such as solar, wind or biomass have emerged as leading alternatives to combat climate change (Lloyd and Subbarao, 2009). To support expansion of these technologies, many governments around the world and supra-national bodies like the EU (Kosenius and Ollikainen, 2013) have implemented public policies (Bird et al., 2002). These include, among others, feed-in-tariff schemes, such as in Germany, France or Japan and quota systems such as in Belgium, Italy, Poland, and the UK (Hansla et al., 2008). These policy initiatives, however, are intended to serve as temporary support mechanisms until renewables become competitive in the energy market.

Competitiveness in any market depends, at least in part, on product pricing. Production costs for most renewables remain higher than those for entrenched fossil fuel technologies and may stay so for the foreseeable future (Ivanova, 2012; Bigerna and Polinori, 2011; Susaeta et al., 2011). Hence, while lowering production costs does represent one strategy to help renewables compete with fossil fuels, a second strategy – convincing both residential and non-residential buyers to pay more for energy from renewable resources – may represent a more promising

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http://dx.doi.org/10.1016/j.enpol.2015.10.001
0301-4215/

approach. This second approach of eliciting a price premium to cover higher production costs requires providers of green energy to develop marketing strategies and tools (Herbes and Ramme, 2014; Nakarado, 1996). These strategies and tools in turn depend on understanding the buyer's willingness to pay (WTP) for the benefits associated with renewable energy use.

Determining WTP represents a significant challenge, with implications both for policymakers who seek to promote renewables through customer demand and for energy providers who seek to promote and cater to that demand. Self-reporting instruments have been the most common tool used to investigate WTP, whether in surveys of private households, which make up nearly 30% of end-user energy consumption in the European Union (European Environment Agency (EEA), 2013), or in questionnaires to non-residential customers. These studies have found that residential customers are willing to pay a premium for green energy, a willingness that may in part stem from the benefit known as the "warm glow of giving" (Menges and Traub, 2009; Clark et al., 2003), which has indeed been found in the context of green energy (Hartmann and Apaolaza-Ibáñez, 2012; Menges et al., 2005). In Germany specifically, past studies have found WTP premiums of ca. 15% (Grosche and Schroder, 2011), of 2.19 EuroCt/kWh (Mattes, 2012) which corresponds to less than 10% and of more than 50 Euro p.a. (only 26% of respondents) (Statista GmbH, 2014). Non-residential customers have also shown a willingness to pay a green energy premium, one that somewhat surprisingly goes beyond the profit-driven assumptions made by neoclassical economics about corporate behavior and incorporates altruistic motives (Wiser et al., 2001). But they may also utilize the fact that they use green energy in their marketing towards their customers.

It is clear from these studies, however, that translating WTP into actual price premiums requires evaluating a complex nexus of socio-demographic and psychographic factors, along with product or scheme attributes and providers' attributes. Energy providers have taken some marketing initiatives in this direction, seeking to differentiate their offerings in a competitive commodity market (Wiser, 1998; Zarnikau, 2003). In some European markets, such as the UK, France or Finland (Herbes, 2014) as well as in the United States (Zarnikau, 2003), energy providers offer 'green tariffs' that contain a variable share of renewable energy. In Germany, one of the most advanced energy markets, hundreds of green tariff products (Herbes and Ramme, 2014) are offered

The efforts of these marketers, as well as those of energy policymakers, would be enhanced were assessments of consumers' WTP to more closely parallel the consumers' actual decision-making processes, a focus of considerable scientific research (Rowlands et al., 2002). To date, however, such research has not studied how neuroscience might be applied to investigations of WTP for green energy. There is good reason to believe a neuroscientific approach holds promise, as neuroimaging has been well established in recent years as an innovative field of marketing research (Müller, 2010; Pradeep, 2010; Shiv and Yoon, 2012; Smidts et al., 2014). Plassmann et al. (2012: 31) contend that analyzing brain patterns promises "better predictions of decision-making behavior across domains" and that decoding these patterns "will be a turning point for consumer neuroscience research."

Neuroscientific studies of price perception have already delivered valuable results in other contexts. For instance, Knutson et al. (2007) used functional magnetic resonance imaging (fMRI) to investigate the neural correlates of purchasing decisions for high-demand products such as popular DVD sets and household items. The authors were not only able to predict the impact of price on purchasing decisions, but found that fMRI-mediated predictions were more accurate than self-reported preferences. Whether such predictions should be restricted to the direct subject of the fMRI or can be generalized to a larger population was later investigated by Berns and Moore (2012), who used fMRI to successfully predict the popularity of a set of new songs. The researchers found that the brain responses from a small test group correlated significantly with the number of units sold in the music market over the next three years, even though the self-reported preferences for these songs were not predictive of sales. In this context, it is interesting to consider the differences between conventional market research and neuroscience based market research. Neuroscience requires millions more bits of information per subject and oftentimes several exposures of the same probe per subject. In exchange, neuroscience manages with significantly less subjects per study. For instance, Berns and Moore used only 27 subjects to predict pop song sales for a 300 million consumer market.

Based on these neuroscientific insights, we have previously developed and validated a tool to measure WTP using neural signals from an electroencephalogram or EEG (Müller, 2012; Thadeusz, 2013). This tool is widely known and branded as "NeuroPricing®". In this study, we apply this tool to investigate consumers' WTP for green energy. Beyond introducing an innovative methodology to the field of green energy, this study also provides insight into German residential consumers' WTP for two green electricity products, one mix product and one pure solar product. German consumers operate in one of the world's most developed markets for green energy, where both mandatory and voluntary support mechanisms prevail. Hence this investigation offers results with important implications from both marketing and public policy perspectives.

This paper is structured as follows: In Section 2 we review existing research with an emphasis on current methods and open methodological issues. In Section 3, we describe the method underlying this study. In Section 4, we report the results, which we discuss in Section 5. The paper closes with conclusions and policy implications in Section 6.

2. Literature review

2.1. Factors influencing WTP

Past research has amply demonstrated that green WTP determinations are complex. Even though the majority of past research has narrowed its focus to residential consumer WTP for green electricity, the influencing factors, as summarized in Table 1, remain numerous.

Clearly, socio-demographic criteria have received wide attention in the literature, where a consensus emerges that higher income as well as education are, not surprisingly, drivers of WTP. Younger consumers tend to be more willing to pay a green premium, whereas the role of gender is inconclusive. A number of psychographic factors also influence WTP; not surprisingly, environmental awareness and related factors, although not always defined in the same way, have been found to contribute to WTP.

Product attributes also influence WTP, although the relative attractiveness of different renewable technologies has not been as widely studied as socio-demographic and psychographic factors. Still, solar seems to be preferred, followed by wind and biomass/biogas, with hydropower being far less attractive. Not only do the product characteristics matter, but also the attributes of the provider, although studies on this are rather scarce. The few existing investigations claim that cooperatives and local providers are more popular with consumers than other types of providers (Sagebiel et al., 2014).

It is obvious already today, that going forward also the choice of the consumer, whether to keep buying electricity from a utility, or whether to become a "prosumer", i.e consuming energy and at the

Table 1
Factors influencing WTP for green electricity.

Category	Influencing factor	Effect on WTP[a]	Authors
Consumers' socio-demographic variables	Age	−/+	Akcura (2013), Aravena et al. (2012), Bigerna and Polinori (2011), Ivanova (2012), Kosenius and Ollikainen (2013), Kostakis and Sardianou (2012), Mozumder et al. (2011), Rowlands et al. (2003), Wiser (2007), Zarnikau (2003), Zhang and Wu (2012), Zoric, Hrovatin, 2012
	Gender: Male	+/−	Akcura (2013), Bigerna and Polinori (2011), Bollino (2009), Champ and Bishop (2001), Clark et al. (2003), Kosenius and Ollikainen (2013), Kostakis and Sardianou (2012), Menges and Traub (2009), Mozumder et al. (2011), Navrud and Grønvik Bråten (2007), Susaeta et al. (2011), Wiser (2007), Zarnikau (2003) Zhang and Wu (2012)
	Income	+	Akcura (2013), Aravena et al. (2012), Batley et al. (2001), Bigerna and Polinori (2011), Bollino (2009), Chan et al. (2011), Clark et al. (2003), Guo et al. (2014), Kosenius and Ollikainen (2013), MacPherson and Lange (2013), Menges and Traub (2009), Mozumder et al. (2011), Oliver et al. (2011), Roe et al. (2001), Rowlands et al. (2003), Wiser (2007), Yoo and Kwak (2009), Zarnikau (2003), Zhang and Wu (2012), Zografakis et al. (2010), Zoric and Hrovatin (2012)
	Education	+/−	Aravena et al. (2012), Bollino (2009), Bigerna and Polinori (2011), Ivanova (2012), MacPherson and Lange (2013), Mozumder et al. (2011), Navrud and Grønvik Bråten (2007), Roe et al. (2001), Rowlands et al. (2003), Susaeta et al. (2011), Zarnikau (2003), Zhang and Wu (2012), Zoric and Hrovatin (2012)
	Household size	+/−	Bigerna and Polinori (2011), Clark et al. (2003), Guo et al. (2014), Mozumder et al. (2011), Zografakis et al. (2010), Zoric and Hrovatin (2012)
Consumers' psychographic variables	Environmental awareness	+/−	Aravena et al. (2012), Batley et al. (2001), Chan et al. (2011), Farhar (1999), Hansla et al. (2008), Hite et al. (2008), Ito et al. (2010), Chan et al. (2011), Kostakis and Sardianou (2012), MacPherson and Lange (2013), Mozumder et al. (2011), Oliver et al. (2011), Rowlands et al. (2002, 2003), Zarnikau (2003), Zografakis et al. (2010), Zoric and Hrovatin (2012)
	Pro-environmental behavior	+	Batley et al. (2001), Kotchen and Moore (2008), MacPherson and Lange (2013), Mozumder et al. (2011), Oliver et al. (2011), Roe et al. (2001), Zografakis et al. (2010)
	Altruism	+	Clark et al. (2003), Ito et al. (2010), Menges and Traub (2008, 2009), Mozumder et al. (2011), Wiser (2007)
	Pro-environmental attitudes	+	Clark et al. (2003), Ito et al. (2010), Kosenius and Ollikainen (2013), Rowlands et al. (2003)
	Information on renewables	+/−	Bollino (2009), Kostakis and Sardianou (2012), Susaeta et al. (2011), Zarnikau (2003), Zografakis et al. (2010)
Product attributes	Source: Solar > Wind > Biomass / Biogas > big hydro	+	Aravena et al. (2012), Borchers et al. (2007), Farhar and Houston (1996), Kaenzig et al. (2013), Kosenius and Ollikainen (2013), Navrud and Grønvik Bråten (2007)
	Percentage of green electricity in the product	(+)	Goett et al. (2000), Grosche and Schroder (2011), Mozumder et al. (2011)
	Voluntary vs. Mandatory	+/−	Akcura (2013), Borchers et al. (2007), Guo et al. (2014), Menges and Traub (2008, 2009), Oliver et al. (2011), Wiser (2007)

[a] Based on our analysis of the sources named in the table: + studies showed positive influence on WTP, (+) studies showed weak positive influence or only for a part of the sample;-studies showed negative influence; +/− means more studies showed positive, but some also negative influence; −/+ means more studies showed negative, but some also positive influence.

same time producing energy e.g. through solar panels; (Huener and Bez 2015) will influence the WTP for the remainder of the needed energy. Moreover, the addition of storage, e.g. batteries or even electric cars (Hu et al. 2013) will further increase the move towards “prosuming” – with potential impact on WTP. However, there is no research for WTP under these novel conditions as of yet – certainly because of the few early adopters of prosuming. But this will be an interesting field of investigation for the future.

Of course, marketing of renewable electricity is always embedded into the larger setting of how renewables are supported in a country and what role they play in the overall energy mix. A solitary study, not represented in Table 1, suggests that respondents' perception of a larger share of renewables in the energy mix of a country may drive down consumers' WTP (Menges and Traub, 2009). In a meta-analysis, Sundt and Rehdanz (2015) also find differences in WTP between countries.

2.2. WTP premiums

The multiplicity of factors influencing consumers' WTP makes it difficult to extract explicit green energy premiums from past research. The samples researchers used were different, the products and schemes presented to study participants were different, and studies took place in different countries where divergent energy policies, value systems and environmental literacies all affected WTP. Moreover, researchers rarely published WTP as a percentage premium over a conventional energy mix, the only premium formulation that generalizes across markets. Therefore, to derive the price points for our study, we recalculated published WTP premiums as percentages, but of course could only do so in those cases where the authors provided the monthly cost of electricity of their participants. Moreover, we only included studies that were fundamentally comparable to this study, i.e.

Table 2
Methods in past WTP studies for green electricity.[a]

Basic method	Question type	Presentation of payment choice	Studies using the respective method
Contingent valuation method (CVM)	Open-ended		Hite et al. (2008), Ivanova (2012), Mozumder et al. (2011), Zarnikau (2003), Zografakis et al. (2010), Zoric and Hrovatin (2012)
	Closed-ended	Dichotomous Choice	Akcura (2013), Aravena et al. (2012), Champ and Bishop (2001), Guo et al. (2014), Hite et al. (2008), Ito et al. (2010), Kim et al. (2012), Kostakis and Sardianou (2012), Nomura and Akai (2004), Oliver et al. (2011), Rowlands et al. (2002), Wiser (2007), Yoo and Kwak (2009), Zografakis et al. (2010)
	Closed-ended	Payment card	Bigerna and Polinori (2011), Bollino (2009), Champ and Bishop (2001), Farhar and Coburn (1999), Rowlands et al. (2003), Zhang and Wu (2012)
Choice experiment and conjoint analysis			Borchers et al. (2007), Goett et al. (2000), Kaenzig et al. (2013), Kosenius and Ollikainen (2013), Ku and Yoo (2010), Menges and Traub (2009), Navrud and Grønvik Bråten (2007), Roe et al. (2001), Susaeta et al. (2011)
Revealed preferences approach (comparing participants in a premium priced green electricity program with a random sample)			Clark et al. (2003), MacPherson and Lange (2013)

[a] *Source*: own desk research based on sources named in the table.

examining WTP for a green electricity product that is purchased voluntarily by residential consumers.

The majority of studies meeting these criteria located the WTP premium between 3% and 19% (Aravena et al., 2012; Borchers et al., 2007; Farhar and Coburn, 1999; Kaenzig et al., 2013; Kim et al., 2012; Ku and Yoo, 2010; Mozumder et al., 2011; Wiser, 1998; Zografakis et al., 2010). Outliers included Guo et al. (2014) at 30% and Mozumder et al. (2011) for their 20% share test at 36%.

2.3. *WTP methods*

Table 2 summarizes the methods used in reviewed studies of WTP for green electricity. Some researchers used multiple methods and may thus appear more than once in the table.

Broadly speaking, three basic methods appear in the literature: contingent valuation, or the stated preference approach; choice-experiment-based, or the indirect stated preference approach; and the revealed preference approach. Contingent valuation methods (CVM), which present respondents with a hypothetical willingness to pay query, can be distinguished by the question type and the presentation of payment choices. Questions may be open-ended, where respondents are simply asked to name the sum they would pay, or close-ended, where respondents are asked to indicate their willingness to pay a specific sum. Closed-ended may be in the form of a dichotomous choice (yes/no to a specific sum) or a payment card (on a card with different sums, circle the largest you would be willing to pay). Finally, methods differ by how respondents are contacted, whether through in-person interviews, telephone interviews, or surveys by mail or online.

Both environmental valuation studies in general as well as studies on WTP for green energy have been dominated by CVM (Bollino, 2009; Navrud and Grønvik Bråten, 2007; Stigka et al., 2014; Yoo and Kwak, 2009; Sundt and Rehdanz 2015). Of the 34 studies we reviewed, 23 used CVM. As evident from Table 2, closed-end dichotomous choice (DC) is the most prevalent CVM design. Choice experiments have also been used; however, our analysis found only two studies using a revealed preference approach, which is understandable since this approach, based on actual consumer behavior, requires a well-developed market for green energy.

Most research has looked at residential consumers, but some has looked at consumers as tourists and their WTP to pay for green energy when traveling (Kostakis and Sardianou, 2012). Some researchers presented respondents with a premium expressed as a percentage (Akcura, 2013). Others presented an absolute monthly premium (Champ and Bishop, 2001; Guo et al., 2014; Mozumder et al., 2011; Zarnikau, 2003) or quarterly amount (Ivanova, 2012; Zografakis et al., 2010,). And still others used an absolute amount per kWh (Goett et al., 2000; Hansla et al., 2008).

Past research has also demonstrated that WTP is sensitive to the quantity, or scope, of the good being offered. Such scope sensitivity appears, for example, in the study by Mozumder et al. (2011), where the researchers found an average WTP of 14 US$ per month for a 10% share of renewable energy in the energy mix, but an incremental WTP for increasing the share to 20% of only 5 US$ per month. On the other hand, the median WTP premium for the 10% scenario was 10 US$ but for the 20% scenario 25 US$, a disproportionately high increase.

2.4. *Problems with current methods*

As prevalent as contingent valuation methods have been in WTP research, equally frequent have been warnings about the problems they present. It has been widely observed that self-reported positive WTPs do not necessary result in large-scale adoption of green tariffs and that WTP is often overstated (Kaenzig et al., 2013; Rowlands et al., 2002; Stigka et al., 2014). Comparisons of WTP survey results with actual participation rates bear this out (Zhang and Wu, 2012). Germany provides a clear example: 66% of consumers report a positive WTP for renewable electricity and 26% say they would be willing to pay a premium of over 50 Euros per year (Statista GmbH, 2014), yet only 20% of households actually subscribe to a green tariff (Rückert-John et al., 2013). Older figures from the U.S. point in the same direction (Zarnikau, 2003).

Various explanations have been put forth for the discrepancies between what consumers say they will do and what they actually do. One is the free-rider effect: if consumers voluntarily pay for an environmental benefit, that benefit serves the entire society, so other individuals can enjoy the benefit without paying for it. They enjoy a “free ride” (Oliver et al., 2011; Zarnikau, 2003). This effect may be significant: Menges and Traub (2009) found a factor of three difference between WTP and willingness to donate (WTD). Other biases that the literature mentions could lead to misrepresenting WTP are discussed in Section 3.1.

3. Methodology

3.1. Counteracting known WTP measurement biases

The neuroscientific methods applied in this study can be expected to avoid or at least mitigate recognized WTP methodology biases, as detailed in Table 3. It should be noted that measuring respondents' neuronal reactions to price points dictates a closed-end research design with dichotomous choice. While this is the most popular CVM design and dichotomous choice is what consumers usually face in market transactions (Champ and Bishop, 2001; Hanemann, 1994), this design may introduce an anchoring bias (Carlsson and Martinsson, 2007; Mozumder et al., 2011). As shown in Table 3, however, the randomized presentation of price points used in this study mitigates such anchoring effects.

This study's choice of varying only one attribute of the energy product presented to subjects – namely the type of renewable technology – further serves to reduce systematic bias and scope sensitivity. More than that, however, this choice is, first, a fundamental one that providers of green electricity have to make when deciding on their product policy as it can play a critical role in the success of their products (Rowlands et al., 2002). Second, policymakers typically differentiate among renewable technologies when designing feed-in-tariff or quota systems (Selder, 2014). And third, as the share of renewables increases, a population develops more differentiated preferences towards certain technologies. In a developed market like Germany, Scandinavia or the United States, intense debate continues regarding the advantages and disadvantages of certain technologies and consumers differentiate one from another (Ladenburg and Dubgaard, 2007; Navrud and Grønvik Braten, 2007; Kosenius and Ollikainen, 2013; Borchers et al., 2007; Rowlands et al. 2002). This behavior has already led to the nearly complete removal of technologies like biogas from the renewable expansion portfolio (Herbes et al., 2014). Most studies on WTP for green electricity do not specify the type of renewable (Sundt and Rehdanz, 2015), therefore we decided to test a mix product since most consumers would imagine a non-specified green electricity product as stemming from several different renewable energy technologies. As the second product we chose a solar product, since solar in past studies was preferred by consumers. Therefore we expected to see a visible difference between the mix product and the solar product.

3.2. Research questions

We sought to answer the following questions:

1. Can a difference be observed between WTP for green electricity stated in an open-ended design and WTP derived from neuro signals?
2. What are the distributions of WTPs for two green electricity products that differ only in their underlying renewable technologies and how big is the difference?

Answering the first question contributes to a better understanding of the biases that so frequently affect empirical WTP research. The second question aims to help both energy providers and energy policymakers. Providers of green energy will be able to better tailor their products to consumers' preferences and WTP. Policymakers will better understand the relative attractiveness of different renewable technologies to the population and so be in a better position to harness consumers' WTP in promoting renewable energies.

Table 3
Potential WTP biases[a] and countermeasures in this study.

Potential bias/problem	How we addressed the issue
Respondents may be unfamiliar with renewable energy (Zarnikau, 2003).	In Germany, renewables are a frequent topic in the media, more than 25% of the nation's electricity comes from renewable resources, and the general public has a high level of awareness of climate change (Andor et al., 2014). In briefing the respondents, we also ensured they understood the various tariffs and energy types.
Respondents may not understand the payment vehicle or accept it as plausible (Morrison et al., 2000).	Germans pay fees using an automatic debit transfer system, so the payment vehicle is well understood.
Bias due to elicitation format (e.g. payment card vs. dichotomous choice). These differences were also found in non-hypothetical decision-making situations (Champ and Bishop, 2001).	We varied the presentation of the price points; however, a limited number of price points were used to avoid overwhelming the respondents.
Anchoring bias (first value presented has an anchoring effect (Bateman et al., 2001; Bollino, 2009)).	Price point sequences presented were randomized within single subject trials and across subjects.
Respondents could simplify the decision making or focus on only one or few attributes resulting in a systematic bias if the products shown are too complex (Alpizar et al., 2003; Navrud and Grønvik Bråten, 2007).	We varied only one product attribute, namely "type of renewable technology".
Respondents could make assumptions about attributes not described in the instructions (Navrud and Grønvik Bråten, 2007).	We varied only one product attribute, namely "type of renewable technology".
Uncertainty bias stemming from respondents' lack of familiarity with the decision scenario (Akcura, 2013; Bigerna and Polinori, 2011).	All respondents were screened for familiarity with comparable decision-making scenarios.
Scope sensitivity of WTP (Mozumder et al., 2011).	The share of renewables in both products was kept at the same level, namely 100%.
Bias due to decision making in a hypothetical situation where the consumer does not consider real-world opportunity costs (Zarnikau, 2003).	The experimental paradigm does not rely on explicit answers.
Strategic behavior: respondents do not answer truthfully because they think they can influence the setting of price in their own interest by understating WTP (Lusk et al., 2007).	The experimental paradigm does not rely on explicit answers.
Difficulty translating percentages or EuroCt/kWh values into real costs (Susaeta et al., 2011) that are easier to imagine (Nomura and Akai, 2004)	Respondents brought actual electricity bills; premium percentages were converted to monthly costs in Euros.
Acquiescence	No sentences were needed to ask questions, instead direct brain response to presented numbers was measured.
Pygmalion effect	Effects related to the experimenter could not be completely controlled because the experimenters were not naïve to the research questions. Subjects, however, were naïve (i.e., a single blinded study design). Moreover, during the test procedure, subjects interacted with a computer while the experimenter observed the EEG recording in another room.

[a] *Source*: own representation based on the sources named in the table.

3.3. Subjects

A total of 40 subjects participated in the study. Data from two subjects could not be used because of technical problems occurring during the experiment. Of the remaining 38 participants, two were rejected from further analysis because of inconsistencies observed in the time needed to react to different price points and three due to noise in the recorded EEG data. The reaction time inconsistencies might have been due to lack of comprehension of the task or to the subjects' not paying enough attention during the experiment. In contrast to experiments in the social sciences, it is standard practice to eliminate noisy data sets. This is because electrophysiological noise is in many occasions of a magnitude that distorts the entire rest of the data set.

Data from the 33 remaining subjects (17 female, 16 male, mean age 37.7, SD ± 15, range 20–70) were further processed and analyzed to determine willingness-to-pay for “mixed green” and “solar only” energy product. Each participant gave informed consent to the study and none of them reported a history of psychiatric or neurological disorders.

3.4. Data acquisition

WTP was investigated both explicitly via questionnaires and neuronally via brain scans. Explicit data were acquired in the first part of the experiment, during which subjects were asked to complete a questionnaire stating how much they would pay monthly for both types of energy products. Brain scan data were acquired using a 64 channel ActiveTwo BioSemi EEG system (BioSemi Instrumentations, Amsterdam, The Netherlands) operating at a sampling rate of 1024 Hz. Subjects sat comfortably in a chair and, after informing them about the safety of the procedure, a BioSemi cap was put on the participants' head, consisting of an elastic cap with plastic electrode holders into which the active electrodes were plugged. EEG was recorded using a standard 10–20 configuration with wet electrodes prepared with conductive gel to ensure optimal quality of the EEG data (Kappenman and Luck, 2010). Each subject's data were inspected by trained neurophysiologists by eye to avoid line noise, muscle artifacts or electric artifacts arising from oculomotor activities. Eye blinks were not calibrated but blink trials were simply dismissed in the offline analysis. For each subject, electrode Cz was placed exactly half way between the two ears as well as between nasion and inion according to the 10–20 configuration. In addition, the vertical electrooculogram was recorded using two electrodes placed above and below the right eye.

3.5. Procedure

Participants arrived for the study having brought along their latest monthly electricity bill, used as described in Table 3. After giving their informed consent, participants attended an information session explaining the features of both “mixed green” and “solar only” energy products. They were then asked to fill out the questionnaires of Section 3.4. An experimenter supervising the questionnaire session was available to provide explanations if needed. After completing the questionnaire, participants were taken to the neuroscience laboratory where WTP for each product was investigated via analysis of brain activity changes in response to different price points.

All participants were tested in two brain scan sessions with a break in between. Six price points were tested for each of the two energy products: 90%, 100%, 110%, 115%, 120% and 130% of the participant's monthly electricity bill. The session order was pseudo randomized between subjects, meaning half the participants started with the mixed energy product followed by the solar energy product and half the other way around. During the experiment, participants were comfortably seated 110 cm from a 27-inch LCD monitor on which stimuli were presented using the Psychophysics Toolbox (www.psychtoolbox.org, Kleiner, 2010; Kleiner et al., 2007) under MATLAB (MathWorks, Natick, MA). Before the beginning of each session, the tested product was carefully explained again to each participant. Furthermore, during each session, a picture explaining the energy product under investigation (“mixed green” or “solar only”) was presented every minute for 6 s on the screen (Fig. 1).

After the explanatory picture, a price randomly taken from the price set was presented. After the price, the word “cheap” or “expensive” was shown randomly. At this point, subjects had to indicate agreement or disagreement by pressing a button. In the context of this study, “reaction time” denotes the time elapsed between the presentation of the word and the pressing of the yes/no button. All subjects were carefully instructed in the procedure, and they were given the opportunity to practice for about one minute before the start of the experiment. During each session, each price point was presented 50 times. Both the brain reaction to each price and the subject's reaction time, were used to investigate WTP for the two products.

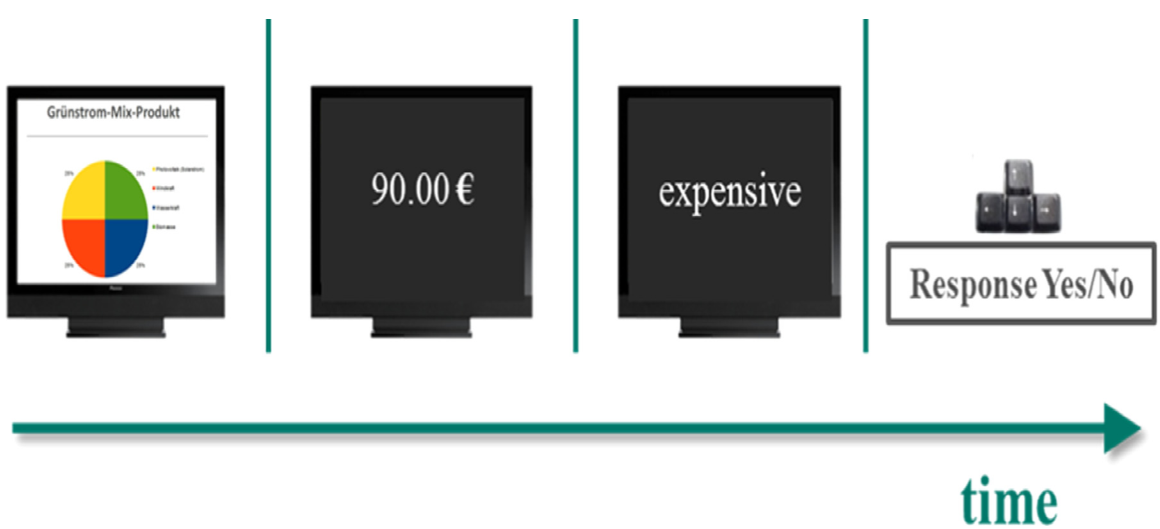

Fig. 1. Experimental paradigm. Each trial in the experiment consisted of a price, an adjective, and a manual response by the subject.

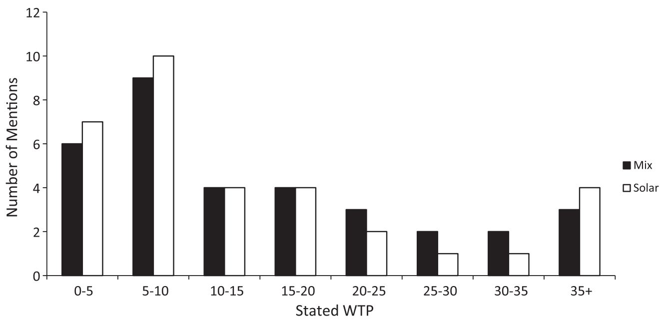

Fig. 2. Explicit WTP. Subjects stated explicitly how much they were willing to pay over their current bill for the respective products and their responses were converted to a percentage premium. Solid bars show the distribution of WTP for the mixed product, white bars for the solar product. A data point was included in a particular bin when the value was greater than the bin's lower bound and less than or equal to its upper.

3.6. Analysis

NeuroPricing® is based on the fact that time-locked EEG signals are an ideal tool to measure match-mismatch signals from the brain. For instance, when presenting a monotonous series of tones, occasionally interrupted by a deviant tone, average EEG signals to the deviant tones will strongly differ from the average EEG signal to the standard tone. Comparable effects have been shown with visual stimuli or language (http://www.jneurosci.org/content/30/46/15578.short, http://www.usc.es/necea/web/uploads/publicacions/arquivo/51e31cfd5a2ed-2003_pazo_etal.pdf). Most time-locked signals are recorded within the first 500 ms after a stimulus appears on a screen. This enables neuroscientists to gather information from the brain that is not filtered and distorted by cognitive processes such as tactical considerations or social influences (see Table 3).

4. Results

4.1. Stated willingness-to-pay

Fig. 2 shows the distribution of stated WTP as a price premium above the participant's current electricity bill. Respondents answered the questionnaires in monetary Euro values, i.e. via an open-ended CVM, and their answers were converted to the percentages shown in Fig. 2. The stated premium averaged 18.5% and 16.6% for the solar and mixed products respectively. These values did not differ significantly ($t(df\ 32)=1.05$, $p=0.3$, n.s., paired t-test). But a number of participants stated a WTP of zero and almost half self-reported a WTP less than 10%. Thus, the average premium values of 18.5% and 16.6% are strongly influenced by those few individuals reporting a high WTP.

4.2. Reaction times

Fig. 3 presents reaction time results. Subjects were not instructed to react quickly, so these times are slower than most in the literature. However, they represent implicit measures, as subjects did not know times were being recorded. The values in Fig. 3 represent the aggregate of four different responses: YES to both the questions "cheap?" and "expensive?" and NO to both questions. Single trial responses above 4.000 ms were excluded, as delays above this threshold did not likely represent respondent thinking. All other responses were averaged to yield the curves in Fig. 3. Reaction time data sets for both the mixed and the solar product peaked at 115%. A 2-way repeated measures ANOVA (Analysis of Variance) was applied to identify differences and interactions between product and price. There was a significant main effect for price, $F(5,11)=2.38$, $p<0.05$, but not for a difference between the products ($F(1, 11)=0.07$, $p=1.0$) or for interaction ($F(5, 11)=0$, $p=0.99$).

4.3. NeuroPricing®

Fig. 4 presents results obtained via NeuroPricing® analysis. Briefly, the responses shown correspond to a brain signal indicating price fairness, a proxy for WTP. In both scientific and industry studies, this approach has proven to be an excellent predictor of population behavior (Conzelmann, 2014; Thadeusz, 2013). In fact, NeuroPricing® has been significantly better in predicting population behavior than reaction times, which in turn are significantly better than questionnaires.

In Fig. 4, the y-axis represents the percentage of the modeled population buying behavior while the x-axis represents the price premium. Peaks are observed at 115%, matching the results seen from reaction times, meaning the majority of subjects are willing to pay a maximum price premium of 115%. A 2-way repeated measures ANOVA revealed a significant main effect for price $F(5,11)=4.33$, $p<0.001$, but as with reaction times, no difference between the two products ($F(1, 11)=0$, $p=1.0$) and no significant interaction ($F(5, 11)=0.44$, $p=0.82$) between product and price.

5. Discussion

This study applied neuroscientific methodology to the assessment of German consumers' willingness to pay price premiums for green electricity. Recognizing the widely publicized limitations on self-reported WTPs, we sought to determine whether self-reported WTPs from an open-ended questionnaire differed significantly from those derived from neurosignals. We further sought to investigate the relative distributions of WTPs for two green electricity products differentiated solely by their underlying renewable technologies.

5.1. Research questions

Our results give a clear affirmative answer to the first research question. Self-reported WTPs from the open-ended questionnaires were significantly lower than those derived from NeuroPricing® analysis. Indeed, more than a fifth of the respondents reported a WTP of zero and another 30% self-reported premiums less than 10% over prices for non-green products. This was somewhat surprising, as we had expected that, due to the biases reported in the literature, self-reported WTPs would have been higher than those derived from brain scans.

One reason for the low self-reported WTPs may lie in the open-ended format used. From the literature, we know that WTP from open-ended designs tends to be lower than that from DC designs. Garrod et al. (1995), among others, observed this pattern, attributing it to respondent perceptions, namely free-rider behavior and the lack of incentive for overstatement. Considering instead the impact of statistical robustness on WTP estimates, Halvorsen and Sælensminde (1998) found that violations of the homoscedasticity assumption in DC studies could explain why these approaches frequently yield higher WTP estimates than open-ended ones.

Yet another reason for these differences may lie in customers' perceiving the process of switching as too cumbersome, a factor already mentioned by Ozaki (2011). Another key to explaining this result might be the specific conditions of the German market, where both voluntary and mandatory schemes exist. Consumers

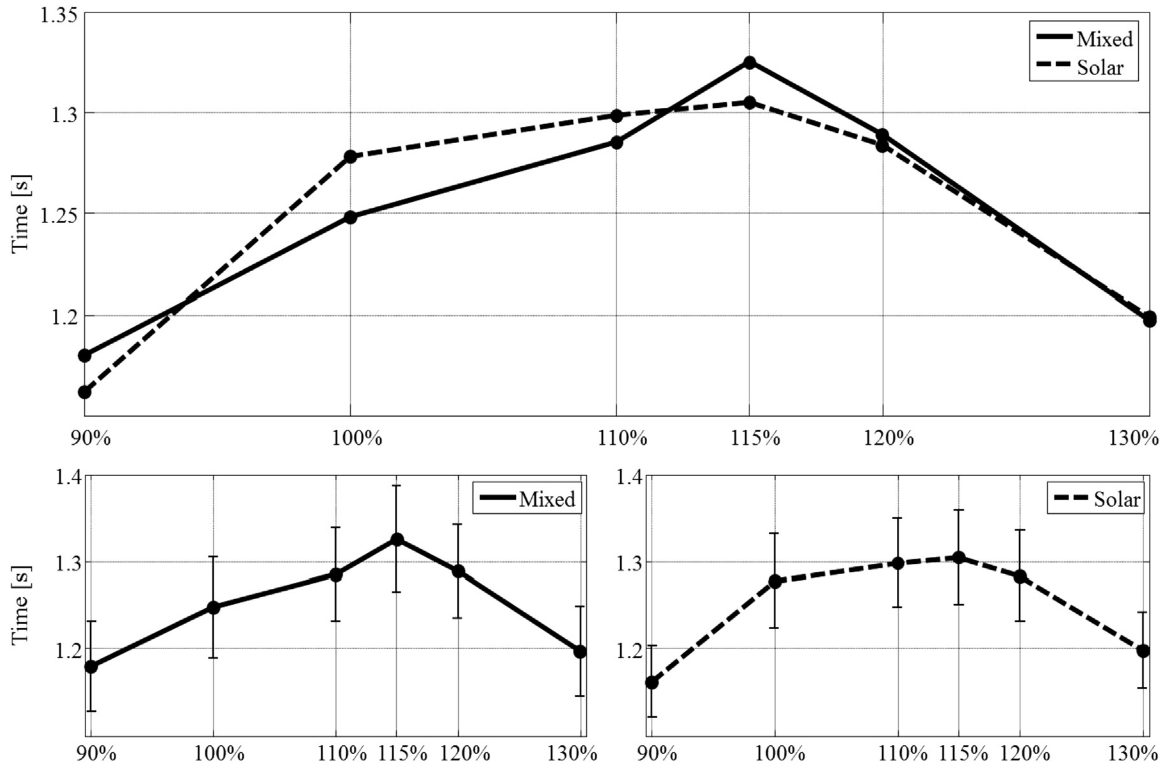

Fig. 3. Reaction time results. The upper panel shows reaction times as a function of relative price. The lower panels show the same data on separate plots with error bars representing standard errors of the mean.

automatically pay the renewable energy levy with their electricity bill, even when not consuming a special green product. Therefore, the low stated WTP might result from crowding out by the mandatory scheme, an effect that has already been described in the literature (Menges et al., 2005; Menges and Traub, 2008, 2009).

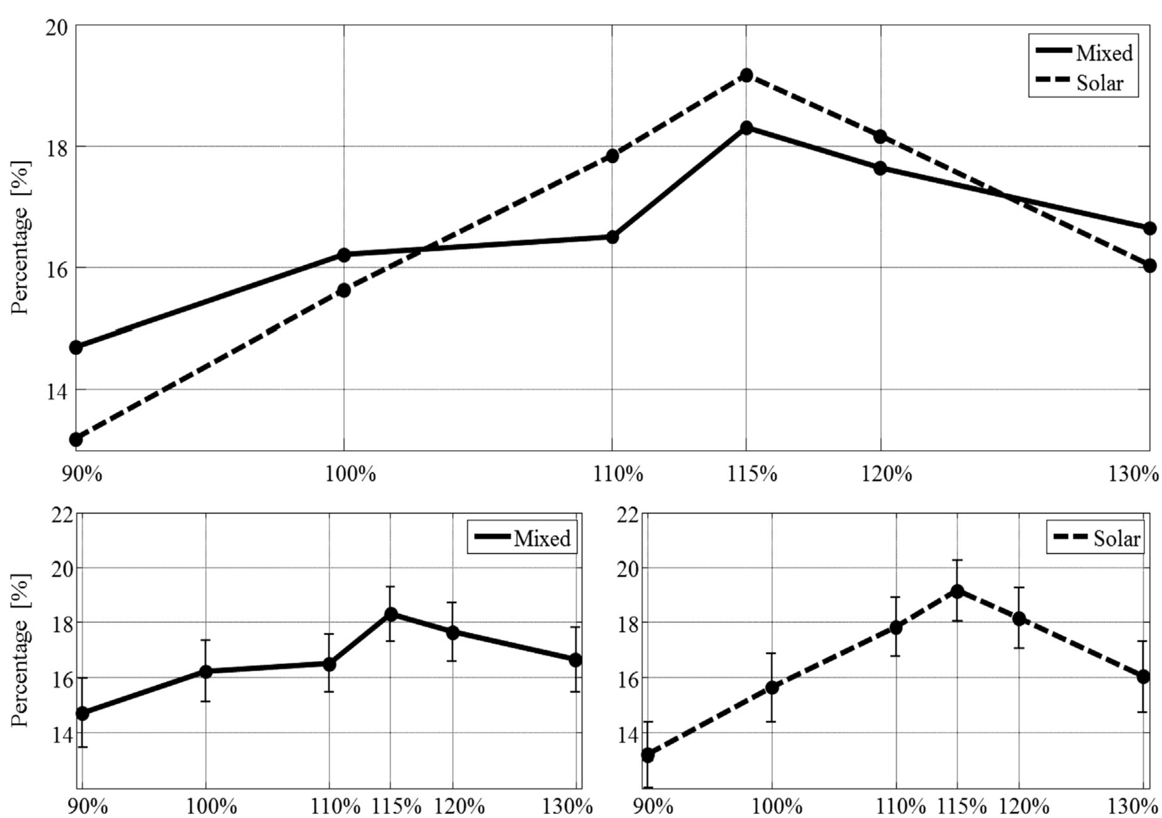

Fig. 4. NeuroPricing® results. The upper panel shows WTP as assessed via NeuroPricing® as a function of relative price. The lower panels show the same data with error bars showing standard errors of the mean.

From a policy perspective, however, there is a deeper meaning in the discrepancy between self-reported WTPs and those derived from neural signals: NeuroPricing® delivers higher WTPs than the explicitly stated WTPs *by the same respondents* and thus apparently avoids the effects of strategic behavior. This yields a fundamental insight. Namely, a range of potential biases in and limitations of self-reported WTPs can be eliminated by our methodology. As brain scans exclude any form of socially desirable or strategic behavior, there is no contingency bias to be accounted for, so the results become more robust. Our study also shows that other potential biases can be neutralized through research design choices (see Table 3).

Marketers and policymakers should also note that the WTP found herein is at the upper end of the range found in previous studies. Those placed the WTP for a green electricity product between 3% and 19%, while our NeuroPricing® research found a WTP of 15% above a non-green electricity tariff. What makes this finding even more significant for energy policy is the fact that prices for household electricity in Germany are some of the highest in Europe, almost 50% above the European average (Eurostat, 2014), a fact that tends to lower WTP (Sundt and Rehdanz, 2015). Under the assumption that the current price per subject reflects their WTP for non-green energy the WTP of +15% shows a significant commitment to green electricity by the study respondents, one that policymakers can potentially harness to increase the share of renewables in the energy market. A counterargument might be made that presenting study respondents with 100% green electricity offers, in contrast to other studies where researched products only contained a share of renewably generated energy, weakens the finding of +15% WTP. However, the German electricity market offers no tariff for "partially green" products, so 100% green offers represent the norm for German consumers, who would always compare these to non-green offers.

Regarding our second research question investigating the relative distributions of WTPs for the mixed and solar-only green products, neither the open-ended questionnaire nor the NeuroPricing® analysis found a significant difference. This is in contrast to earlier studies, where the solar product always achieved a higher WTP. A likely explanation for this result is the current market in Germany, where most green electricity products rely on certification to support their green claims (Leprich et al., 2015). These certificates do not communicate details about the origin of the electricity. Hence the very familiarity of these products to German consumers means they tend to view the products as interchangeable, as far as the origin of the electricity is concerned. Current strategies of green electricity providers seem to match this consumer view. Most green electricity products in European markets consist of Scandinavian certificates from old hydropower plants (Herbes, 2014). While consuming these products does not contribute towards limiting global warming, consumers still perceive them as "green".

Another observation regarding the relative distribution of WTPs concerns the fact that results from our study appear to be relatively flat, which differs from distributions found in most other non-published NeuroPricing® studies. One possible explanation for this is that our study focused on green energy, about which there exists a broad spectrum of opinions as well as a broad range of factors influencing purchasing decisions. These might manifest in an equally broad distribution of WTPs.

5.2. Sample size and significance of results

In comparison to previous studies on WTP in the energy sector, this study used a much smaller sample size. That is an advantage of the cognitive neuroscience approach, where sample sizes are typically in the lower two-digit range (Button et al., 2013; Karl et al., 2006; Osman et al., 2005). In contrast, quantitative survey-based research studies often require as many as 1000 representative citizens.

The appropriate number of study participants is a question related to statistical power, which depends on several parameters (Cohen, 1992, 1994). In event-related EEG experiments (Luck, 2014) and related analysis such as used here, the crucial parameters are: (1) number of test subjects; (2) number of presentations per condition for each subject; (3) kind of the statistical test; (4) size of the experimental effects; (5) level of noise or variance; and (6) desired significance level of the analysis.

Unpublished industry research on NeuroPricing® gave us estimates for some of these parameters; the research design decided the others. This study used: (1) 30–40 subjects, a cohort size previously found sufficient to detect significant differences; (2) 50 trials, found sufficient for stable subject responses; and (3) a 2-way ANOVA, which yielded clear results. The size of the experimental effect (4) as well as the noise level (5) depend on how far apart the price points are and how strongly the WTP varies across individuals. Price point intervals were set by the experimenters, while variance across individuals could only be answered post hoc. As for desired significance level (6), we initially would have been satisfied with results on a level of $\alpha=0.01$, so our results clearly outperformed our goals. This indicates that more subjects would not have improved the results. In fact, if anything, we oversampled and might have used even fewer subjects.

5.3. Recommendations for future research

Because we wanted to limit the number of trials presented to the test subjects, we did not test the non-green product with the NeuroPricing® scans, but only the two different green electricity offers. A future study might test the non-green product and so allow for an even better embedding of neuroscan results within the research. A second interesting direction would be to find better methodological ways to combine the DC questions used in NeuroPricing® analysis with open-ended questions to shed further light on motives for and opinions behind the WTP results.

Now that the applicability of NeuroPricing® to the energy market has been established, both marketers and policymakers could find it valuable to use neuroscans to investigate prosumer leasing model preferences for roof-top solar panels – the most likely form of solar-only electricity to be offered in Germany in the near future. Neuroscience could also be used to test different green product certificates to gain further insight into the type of assurance consumers require to pay more for green energy. Further studies using NeuroPricing® could examine how marketing communication strategies influence WTP. Finally, respondents could be grouped into customer segments based on existing WTP studies. This would probably result in less variance within the groups, implying a more prominent peak in the NeuroPricing® curves.

6. Conclusions and policy implications

For the first time, WTP for green energy was investigated by neuroscience. Resulting WTPs fell within the range found in studies employing other valuation approaches; however, the methodological limitations of those studies were largely neutralized. Importantly, neuroscience requires far fewer respondents to arrive at reliable results than do traditional research methods. Thus, we have presented an innovative research design for estimating economic values, one suitable for investigating broader questions related to energy marketing and energy policy.

Marketers can take away two results from this study. First, the WTP of consumers is apparently higher than the average 2%

premium that green electricity products in Germany today carry on average. This opens opportunities for creating higher-value green products and marketing them at a higher premium, which in turn creates new outlets besides the subsidized feed-in-schemes that many renewables use today. The results herein might even support further development of the prosumer solar energy models recently launched in Germany (Friege, 2015; Rutschmann, 2014). The second key fact for marketers to take away from this study concerns the ability of NeuroPricing® to enhance existing approaches to consumer research. NeuroPricing® appears to neutralize strategic behavior bias from respondents, allowing marketers to more realistically assess the WTP of their prospective customers. NeuroPricing® could even be used to magnify the granularity of WTP research, examining, for example, detailed product features such as proven regional origin or the effects of specific claims in marketing communications.

Architects of renewable energy policy can take away new insight into the relative importance of green power marketing in supporting the transition to renewable energy. Given the fact that all electricity tariffs in Germany, including 100% green electricity products, carry a hefty subsidy to support investments into wind and solar ("EEG-Umlage") – a subsidy currently standing at 6.17 Cent/kWh and together with additional small items and VAT accounting for more than 25% of the average electricity price – it is remarkable and encouraging that consumers are still willing to pay more for a green electricity product.

Moreover, the findings of this study can encourage the opening of other regulatory pathways, such as a more flexible regulatory framework for solar energy produced on the roof of multi-tenant dwellings and then used by some or all tenants in the building. The WTP especially for a solar only product allows for the flexibility to satisfy all parties involved in such cases.

Finally, the WTP results from this study confirm the most recent regulation in the EEG 2014 about direct selling ("Direktvermarktung") of electricity generated with EEG subsidies. Here, additional room for pricing the directly marketed electricity and thus also room for a further reduction of the renewable energy levy ("EEG-Umlage") can be read into our findings. Current legislation under the German Renewable Energy Act prohibits sellers of green electricity from using the green attributes of those products in marketing. Allowing them to use the "greenness" of their products would create opportunities for providers to develop and test marketing strategies while still receiving partial public policy support. This in turn may help providers to become independent of subsidies in the long run (Herbes and Ramme, 2014).

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