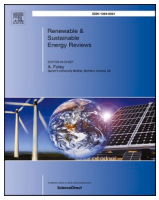
Renewable and Sustainable Energy Reviews 162 (2022) 112419

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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



Pricing decisions in peer-to-peer and prosumer-centred electricity markets: Experimental analysis in Germany and the United Kingdom

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ARTICLE INFO

Keywords:
Peer-to-peer trading
Energy communities
Price setting
Cross-national research
Trading decisions
Peer-to-peer actor
Trust
Place attachment
Political orientation
Digitalisation

ABSTRACT

Prosumer-centred electricity market models such as peer-to-peer communities can enable optimized supply and demand of locally generated electricity as well as an active participation of citizens in the energy transition. An important element of active participation is the improved ability of community members to identify and choose who they transact with in a much more granular way than is usual. Despite this key novelty and the social core of prosumer-centred markets, little is known about how citizens would trade with different actors involved in the system. This article reports a preregistered cross-national experiment investigating individual trading preferences in a peer-to-peer community with a variety of private and non-private trading actors. The data from the United Kingdom (n = 441) and Germany (n = 440) shows that set buying and selling prices strongly vary, pointing to three systematically different trading strategies that individuals apply as a function of involved trading actor. Findings moreover reveal that trading decisions are determined by individuals' political orientation, place attachment, and climate change beliefs as well as individual differences in trust in the involved trading actor. Finally, the results illustrate high consistency in trading preferences across nations. However, nation-level differences emerged when decisions were made publicly visible, emphasising the need to consider context-effects in peer-to-peer system design. The findings have implications for the development of prosumer-centred energy models and the design of interventions to increase citizen participation across national contexts.

1. Introduction

Recent years have seen the emergence of prosumer-centred electricity market models such as peer-to-peer (P2P) trading and local energy markets [1–5]. These involve prosumers and consumers making electricity transactions directly between each other, or within relatively small local groupings [6]. Such models are characterised by improved ability of system users to identify and choose who they transact with in a much more granular way than is usual [7]. It is this characteristic, and its possible implications, that motivate the research presented here.

Today's centralised retail electricity markets mostly involve small users purchasing electricity indirectly from a small number of large, asset-owning generators through a single supplier. In a Prosumer-Centred Model (PCM), depending on the design of the scheme, participants may be able to transact not just with, for example, users they know to be local, but potentially specific individuals or groups [7,8]. For example, services could attract customers with the option of trading at reduced rates with friends and family, or supporting a local school by purchasing power at a price premium from them [9].

A substantial amount of research effort in recent years has been directed at understanding how PCMs can be designed to support network management [3] while also delivering user benefits such as reduced bills [10]. Increasingly, attention is also being paid to the role of participant decision-making in such trading [11–13]. However, limited previous research has examined how people's trading preferences vary depending on the P2P trading actor involved in the transaction (for exceptions see [9]).

The aim of the present research is therefore to investigate whether people set different trading preferences for different actor groups participating in a P2P-based PCM, and to explore psychological factors underlying their decision preferences. A further goal is to examine whether changes in the choice setting, that is whether or not participants were informed that their decisions are publicly visible, influence trading decisions. Taken together, the following preregistered research questions are addressed by means of nationally representative experiments in Germany and the UK:

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https://doi.org/10.1016/j.rser.2022.112419
Received 13 December 2021; Received in revised form 8 March 2022; Accepted 29 March 2022
Available online 25 April 2022

List of abbreviations

DER	Distributed Energy Resource
P2P	Peer-to-Peer
PCM	Prosumer-Centred Model
UK	United Kingdom
ICT	Information and Communication Technology

1. Do people set different energy trading price preferences with different PCM actors and, if so, why?
2. Is there a difference in set trading price preferences depending on whether preferences are publicly visible or not?
3. Are there country-level differences in set trading price preferences?
4. How do set trading price preferences vary with respondent characteristics (demographic, psychological traits, psychological trading-specific variables, respondent-actor relations)?

The next Sections 1.1 and 1.2 review previous research relevant to these questions, including research on the willingness to share energy and determinants of trading decisions. Sections 2 and 3 describe the methods, including the sample (Section 2.1), measurements (Section 2.2), the P2P scenario tasks and experimental manipulations (Sections 2.3–2.5) as well as the preregistered analysis strategy (Section 3.0). Sections 4.1–4.3 describe the findings with respect to Research Questions 1–4. Study reporting broadly follows the CONSORT guidelines for reporting of randomised control trials [14]. Finally, Sections 5.1–5.4 discuss the implications of the findings for theory, policy, and practice and Section 6 provides the key conclusions.

1.1. Willingness to share energy in prosumer-centred models

The electricity consumed by users has mostly obscure origins. It may have been generated by a nuclear reactor, by burning methane, or by a wind turbine – and the generator could have been situated locally or in another country [15]. Whatever the source, it appears as a homogeneous commodity. In recent decades, customers have had the choice of purchasing power from renewable generators [16]. In early 2021 these accounted for over half of tariffs on offer in the UK [17]. While there are questions around the origin claims made for renewable tariffs, there is clear demand for products that permit choice of energy source and the expression of non-financial motivations [18].

Advances in metering and information and communication technology (ICT) now offer the prospect of much finer grained tracking of the origin and destination of electricity – at least for accounting purposes [6]. In combination with rises in the penetration of distributed energy resources (DERs), this has led to the emergence of PCMs such as P2P electricity trading [1,7]. While real examples of such schemes are still mainly limited to small field trials, they are the subject of substantial interest in research, policy, and practice. Consumer research suggests they are popular in principle, with studies consistently finding stated interest in participating in the order of 50–80% [8,12,13,19,20].

While P2P electricity trading does not necessarily have to take place within a locality, this is the most common use case (e.g. Ref. [21]). Mixed evidence is emerging as to the value placed on local electricity. In a German choice experiment Mengelkamp et al. [22] found that both greenness and localness in electricity were somewhat valued. The results differed for an all-Germany and a regional sample (Allgäu). Except for a slight willingness to pay more for regional electricity in the regional sample, there was no indication that localness was viewed as a premium characteristic for which participants would actually pay more. Wörner et al. [23] worked with 31 participants in a real P2P trading scheme, exploring an actual setting of buy and sell prices. In a pre-survey, around half the participants suggested they would be prepared to pay a premium for local renewable generation. However, with some temporary exceptions, real-world price settings generally indicated a lack of inclination either to pay premium prices for local renewable energy, or sell at a discount that would take the price below that received through the feed-in tariff. The limited evidence available so far therefore suggests that little if any premium is placed on local over non-local electricity [22–24].

When more information about the identity of local trading actors is introduced in research, a nuanced picture emerges. In interviews conducted by Pumphrey et al. [25], some participants expressed concern about doing financial business with neighbours, because of the personal conflict that could result. A survey experiment by Fell et al. [8] also found that people were more likely to participate in trading schemes that operate at a city or region level rather than hyper-local level. However, for some the idea of trading with neighbours is an attraction to participate, as found by Scuri et al. [26], in a study of ten households on the Portuguese island of Madeira. Even there, however, some preference was expressed for donation rather than payment, out of respect for the neighbourly relationship.

This nuanced dynamic was further highlighted in an ethnographic study reported by Singh et al. [27], who studied sharing of access to solar generation for uses such as mobile phone charging in rural India. Participants' preference for financial or other (more social) forms of exchange differed depending on the relationship between them, with financial returns preferred for more distant connections, and more social in-kind or intangible returns preferred for closer relationships. There is some support in existing research for a preference to trade with specific households. A study by Wilkinson et al. [28] used focus group discussions with participants in an actual P2P trading scheme in Australia to explore their perceptions and motivations. A key desired feature highlighted by the participants was the ability to trade with or support selectively other participants. Again, concern was expressed about the unequal ability to benefit, and there was a general dislike for the strongly market-driven (rather than community centred) nature of the scheme.

A range of more general motivations are highlighted in an interview study by Wilkins et al. [29]. Here, the ability to trade with others in a locality is viewed by some as a way of building community cohesion, taking power back from large corporations, and promoting engagement in sustainability. However, there is again evidence of concern around the introduction of financial elements to relationships that lacked them previously. Such a concern would be that certain participants gaining power over others through having the ability to set (rather than take) prices. There were mixed views on the role of such schemes in addressing social challenges. Some participants saw potential in the ability to provide power prices to participants in fuel poverty. Others were concerned by the dependency this would introduce on the altruism of others rather than more traditional centrally coordinated alleviation mechanisms. This discomfort with the idea of delegating too much socio-economic work to P2P communities is also present in a workshop study by Smale and Kloppenburg [30]. There was little appetite for using the communities as a redistributive mechanism, with a preference for using them to deliver some shared community objectives, such as facilities. However, research using a discrete choice experimental approach on a small ($N = 72$) sample of prosumers in the Netherlands found a high (50%+) degree of willingness to donate excess electricity to low income households and community facilities [9].

Ecker et al. [11] experimentally investigated whether the price at which German participants would be willing to buy or sell electricity with neighbours differed depending on benefits framing. They found that participants set significantly lower buying prices and higher selling prices when autarky (independence of electricity supply) benefits were emphasised compared to a neutral condition. Hahnel et al. [12] built on this work to explore the more dynamic impact that current electricity price and the state of charge of a home battery have on trading decisions. Three main trading clusters emerged: some participants mainly based

their decisions on price, others mainly based their decisions on state of battery and some participants only traded when the state of charge exceeded a certain threshold.

Taken together, the literature suggests an interest in principle in engaging in P2P trading, with some appreciation of local electricity but limited willingness to pay more for it, and mixed willingness to trade electricity with friends and neighbours. The present research aims to extend this work by unpicking further the influence of the identities of local actors on people's trading preferences. This includes both domestic actors, such as neighbours and friends, but also non-domestic ones such as companies and public organisations like schools and hospitals. These organisations have the potential to become key players in local energy trading schemes due to their access to the space and economies of scale to install larger energy assets [31]. Here, this is explored through an experimental online study, which requests participants to set default trading prices with a range of actors in a P2P scheme. This represents a halfway-house between active trading and no involvement in price-setting, both of which have been shown to be popular options in a real-world P2P trial [21]. In contrast to most previous research, the present study examines both selling and buying conditions (for exceptions see Ref. [11]). This design allows to not only investigate differences in volatility in set selling and buying prices but also to investigate trading decision-making strategies in more detail. As outlined in the next section, this includes reciprocal, altruistic, and non-cooperative decision patterns as a function of the trading actor at hand.

1.2. Determinants of trading decisions in prosumer-centred models

The key novelty of PCM is the incorporation of the social dimension into energy supply and consumption [7,13]. Handing over decision power to private actors requires cooperation among community members in order to ensure a functioning decentralised market [12]. Fundamental theories on direct reciprocity suggest that human cooperation is built on an equilibrium of cooperation and defection among individuals [32,33]. Direct reciprocity implies the assumption that cooperation will ultimately lead to cooperation, whereas defection will ultimately lead to defection. Research using economic games has accumulated evidence for associated tit-for-that mechanisms in human cooperation and illustrated that humans are willing to spend their own resources in order to punish group members that deviate from this principle [34,35]. Early research has indicated that such basic principles underlying human cooperation also apply to the context of P2P energy trading [11]: Homeowners set statistically identical buying and selling prices for self-generated electricity; a strategy associated with a tit-for-that principle. However, when their own independence was made salient by means of an experimental manipulation, homeowners shifted from this cooperative strategy to a noncooperative trading strategy in that they set higher selling prices relative to buying prices [11].

Trust is an essential component in highly cooperative environments such as PCM. Definitions of trust vary, but in the context of this research trust may be usefully understood as: "The willingness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other party" [36] (p. 712). Trust is relevant in P2P trading schemes. Members may set the terms on which they would be ready to trade with others, but they are dependent on others' terms for trades to actually take place [7]. For example, Community Member A may offer discounted energy to Member B and expect to get a discount in return – but while Member B would definitely realise a saving in this case, Member A's saving is dependent on Member B also choosing to offer a discount. In setting her default terms, Member A must trust Member B to display reciprocity [33]. While trust in energy suppliers has previously been shown to be associated with preference for participation in a range of electricity demand response offerings [37,38], its role has not yet been systematically explored in the context of P2P trading decisions. In light of the various actors involved in PCMs such as P2P energy schemes, it is key to understand how trust impacts trading decisions of community members as a function of the trading actor at hand.

Whereas direct reciprocity has been proven to be a powerful mechanism in human cooperation, it is ultimately limited in its ability to explain mere altruistic acts [32]. The principle of indirect reciprocity provides a theoretical account for altruistic decisions in social groups [39]. The main assumption is that altruistic acts, without direct rewards, may nevertheless pay out by increasing the reputation of the giver, which in turn will be rewarded by others. In accordance with this, there is evidence that making people's decisions public results in more prosocial behaviour, such as more generous charitable giving [40,41]. Price can be an important form of social signal, in which the identity of the giver and receiver are both key considerations [42]. Knowledge of identity is thus an enabler of indirect reciprocity (based on acting to uphold reputation) [43], and is an essential consideration in approaches which view trading through a lens of behavioural game theory, which is concerned with departures from standard ideas of economic rationality [44]. To test the role of trading choice visibility, a between-subjects experimental factor was introduced to the present study: one group was informed that their trading choices in the PCM would be visible on the platform, while another group was told their choices would remain confidential. We hypothesised that in the publicly visible condition, participants will set higher buying prices and lower selling prices compared to the private condition.

Cooperation behaviour is context dependent [45–47]. For instance, research administering behavioural experiments across 15 populations has shown that contextual factors such as community size and market characteristics predict fairness and costly punishment in cooperation tasks [45]. In another study across 16 international populations, norms of civic cooperation and the rule of law predicted behaviour in public goods experiments [47]. The present research accounted for national context by simultaneous experimental data collection in two countries – Germany and the UK. In addition to exploring the role of national context, this approach allowed to improve the international generalisability of the findings. With some exceptions (e.g. Ref. [22]), most previous research has focused on a single country or locality [9,11,12,19], limiting the extent to which the role of context factors and cultural differences can be explored. The relevance of the local context is further reflected in the concept of place attachment. Place attachment has been linked to positive affective bonds to local groups and communities and a stronger identification with local actors [48]. Given the local nature of the PCM analysed here, we assumed that stronger individual place attachment is associated with stronger cooperation behaviour.

In addition to differences in place attachment, research has revealed further interindividual differences that directly or indirectly shape cooperation and altruism. Political orientation has been linked to differences in the perception of social inequality, the relevance of fairness, and variation in market and system justification beliefs [49,50]. We assumed that associated fundamental differences in belief systems underlying political orientations account for significant variance in trading decisions [12]. The present research tests the assumption that the impact of political orientation on decision outcomes largely depends on the involved trading actor. Cooperation with multinational companies, for instance, should depend on the extent to which the decision maker considers the actor to be a crucial element of the economic and social system; a belief that is formed by market and system justification beliefs [49]. Finally, given the relevance of PCM as an instrument to reduce carbon emissions [51,52], the present research investigates whether differences in climate change beliefs explain variance in trading decisions. This approach is further in line with the fundamental assumption that environmental and altruistic concerns and values are largely interconnected [53,54].

Taken together, basic research on human cooperation has shown that direct and indirect reciprocity are fundamental principles underlying human cooperation behaviour [32,33,35,39]. We infer three decision

patterns from the literature and assume individuals to apply these patterns in the context of PCM: *tit-for-tat*, *noncooperative*, and *altruistic* decision patterns [11,32,41,55]. The present preregistered research investigates whether individuals apply different trading decision patterns in PCM as a function of the trading actor at hand and examines under which conditions trust modulates this decision-making process. The study also examines the role of public visibility on trading decisions, grounded in the finding that reputation is a basic principle of cooperation. This research finally accounts for the finding that context shapes cooperation decisions as well as for the impact of interindividual differences such as place attachment and climate change beliefs on decision-making. The next section describes the method employed in the research.

2. Material and methods

The procedure of the present study is illustrated in Fig. 1. After providing their informed consent, participants answered a series of demographic questions (see Section 2.2) and then read the P2P scenario introduction (see Section 2.3) in which they either were informed that their choices were private or public, depending on random experimental variation. Afterwards, participants conducted the P2P trading task (see Sections 2.4 and 2.5) and finally conducted a post-survey (see Section 2.2). The preregistration report, study data and code as well as the full study material are publicly available on the Open Science Framework: https://osf.io/cau9v/?view_only=d92aaa2c8a9540bda8b9361ea75f98e6.

2.1. Sample

In total 881 participants from the UK (n = 441) and Germany (n = 440) took part in the online study from December 7–13, 2020. Aiming for representative samples of the UK and German population, data was collected by a professional market research institute with participant panels in both countries. Quotas on age and gender were applied.

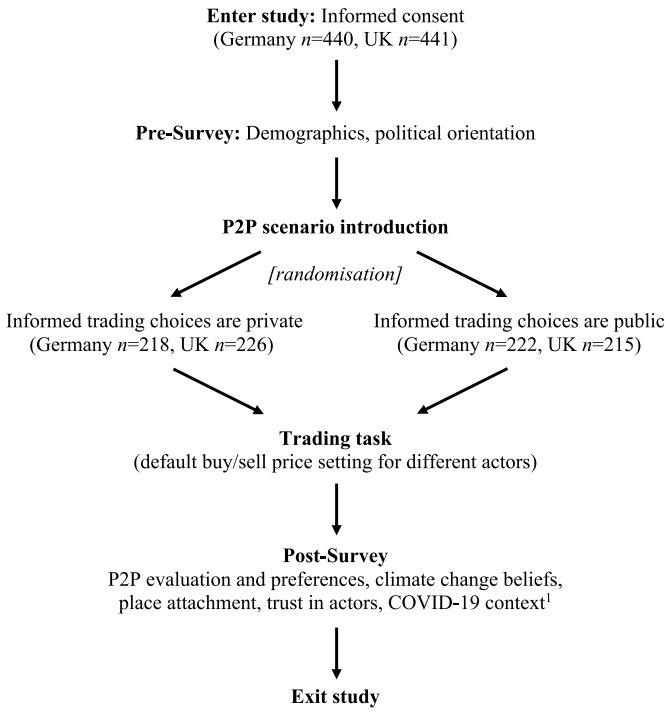

Fig. 1. Design of the present study, including the between-subjects experimental variation. Data was collected in the UK and Germany (N_{total} = 881). [1]For a complete list of assessed variables see: https://osf.io/cau9v/?view_only=d92aaa2c8a9540bda8b9361ea75f98e6.

Participants received financial compensation for taking part in the study that took around 15 min. Only participants over 18 years were eligible to take part in the study. Descriptive statistics for the UK and German subsamples are depicted in Table 1. The study was approved by the ethics committee of the Faculty of Psychology and Educational Sciences of the University of Geneva, Switzerland. All participants gave their consent to take part in the study. As research on P2P energy trading preferences is still scarce, sample size was not determined on the basis of being able to detect a pre-specified effect size. Rather, it was determined by the resources available. Sample size has been predefined and reported in the preregistration report.

2.2. Demographics and psychological measurements

At the beginning of the study, participants answered a series of demographic questions including age, gender, political orientation, education, and employment status (Table 1). After the trading task, participants' climate change beliefs and place attachment were assessed using adapted versions of validated scales [56–58]. Climate change beliefs ("e.g., "Climate change is likely to have a big impact on people

Table 1
Characterization of the UK and German samples. Values reflect frequencies and mean values with standard deviations in parentheses. Statistically significant differences between the German and UK sample are marked in bold.

	Germany (N = 440)	UK (N = 441)
Sex		
Female	50.2%	50.1%
Age	46.72 (16.9)	45.97 (16.5)
Employment status		
Student	9.3%	6.1%
Unemployed	**3.9%*****	**10.7%*****
Full-time	43.6%	48.5%
Part-time	11.4%	14.5%
Retiree	21.4%	16.3%
Other	**10.5%*****	**3.9%*****
Education		
Primary school	**8.9%*****	**0.2%*****
Secondary school	**30.9%****	**21.8%****
Further education	25.5%	23.8%
Higher education/Undergraduate	**13.4%*****	**35.4%*****
Higher education/Postgraduate	18.6%	18.1%
Other qualification	**2.7%***	**0.7%***
Household members	**2.21 (1.12)*****	**2.59 (1.36)*****
Energy mix		
100% renewable	30.0%	31.7%
Fossil/renewable mix	**41.6%*****	**29.3%*****
Do not know	**28.4%****	**39.0%****
PV possession	9.1%	8.4%
Purchase intention[a]		
PV	**2.62 (2.02)*****	**3.15 (2.08)*****
ESS	2.61 (2.03)	2.80 (1.89)
Political orientation[b]	**4.97 (1.63)***	**5.23 (1.86)***
Climate change acceptance[c]	**5.14 (1.18)****	**4.88 (1.09)****
Place attachment[d]	4.91 (1.17)	4.82 (1.27)
COVID-19		
Daily routines[e]	3.3 (1.19)	3.41 (1.22)
Financial situation[f]	2.85 (0.76)	2.82 (0.93)

Note. PV = photovoltaic system, ESS = energy storage system.
***p < .001; **p < .01; *p < .05.
[a] Technology purchase intention (within next 5 years) ranged from 1 – *very unlikely* to 7 – *very likely*.
[b] Political orientation ranged from 1 – *extremely left* to 10 – *extremely right* [59].
[c] Climate change beliefs ("Climate change is likely to have a big impact on people like me.") varied from 1 – *strongly disagree* to 7 – *strongly agree* [56].
[d] Place attachment (e.g., "My local area means a lot to me") ranged from 1 – *strongly disagree* to 7 – *strongly agree* [57,58].
[e] COVID-19 change daily routines ranged from 1 – *very small extent* to 5 – *very large extent* [60].
[f] COVID-19 change in financial situation ranged from 1 – *lot worse* to 5 – *lot better* [60].

like me.") and place attachment (e.g., "My local area means a lot to me ") were measured with seven items each on a scale ranging from 1 – *strongly disagree* to 7 – *strongly agree*. Participants' trust towards the key actors involved in the P2P trading tasks was further assessed (i.e., schools and hospitals, small businesses, large multinational companies, low-income households, groups of friends and family, and direct neighbours). Trust was measured using the item "How trustworthy do you consider each of the following groups?" and was answered for each actor individually on a scale ranging from 1 – *very small extent* to 5 – *very large extent*. Also, participants reported their current energy mix and PV system possession. The original version was developed in English and translated by native speakers to German for data collection in Germany.

2.3. P2P scenario introduction

After providing demographic information, participants were forwarded to the P2P trading scenario. Given that most individuals had no experience with P2P communities at the point of data collection, this section was designed to provide participants with a realistic image of a possible P2P community in a clear and understandable manner. Participants were asked to imagine that they have just moved within their local area into a new home with solar panels on the roof, allowing them to generate their own electricity with their own PV system. It was further explained that participants were already part of an energy network scheme called *PowerClub*, run by their local authority. This scheme let members trade (i.e. buy and sell) electricity they produce, but do not need themselves, directly between each other. Members were people and organisations in the local area who wanted to sell their renewable energy or buy renewable energy from local actors. The purpose of the scheme was to support uptake of low-carbon power sources, and help manage the local electricity network.

Participants were further informed about the group of people and organisations taking part in the network: direct neighbours (i.e., the ten nearest households), a selected group of local friends and family members, local low-income households (e.g., people living in social housing), schools and hospitals, small businesses (e.g., local shops), and large multinational companies that have offices in the local area. As members of the scheme *PowerClub* participants had the opportunity to set their trading preferences with different groups of people and organisations. Specifically, they could choose the price at which they wanted to trade electricity with each group (i.e., set buying and selling price for each actor). It was experimentally randomised between subjects whether participants were informed that their selling and buying preferences were made publicly available on their profile ($n = 437$) or were only visible in their private profile ($n = 444$) and thus whether or not their decisions were visible by the other members of the scheme.

2.4. P2P trading tasks

After the introduction section, participants set their preferred buying and selling prices for each group of community members. The order of trading tasks (buying and selling) was randomised. See Supplementary Note 1 for additional information on the task.

In the buying condition, participants were asked to set the unit price (i.e., 1 kWh) at which they would be willing to buy surplus electricity from the groups taking part in the *PowerClub* scheme (i.e. the price they would be willing to pay). Participants could choose to (i) buy electricity from the groups at the default electricity price of the scheme (i.e., 15 pence/kWh and 30 €Cent/kWh in the UK and Germany, respectively), (ii) offer groups a premium, or (iii) ask them for a discount using a scale ranging from −5 pence/kWh [€Cent/kWh] to +5 pence/kWh [€Cent/kWh) with default unit price as midpoint [61,62]. That is, positive values reflected that participants offered a price premium and negative values reflected that participants asked for a discount.

In the selling condition, participants were asked to set the unit price at which they would be willing to sell their surplus electricity to the groups taking part in the *PowerClub* scheme (i.e. the price the groups would pay). Participants could choose to (i) sell electricity to the groups at the default electricity price of the scheme (i.e., 15 pence/kWh and 30 €Cent/kWh in the UK and Germany, respectively), (ii) ask groups to pay a premium, or (iii) offer them a discount using a scale ranging from −5 pence/kWh [€Cent/kWh) to +5 pence/kWh [€Cent/kWh] with default unit price as midpoint [61,62]. That is, positive values reflected that participants asked for a price premium and negative values reflected that participants offered a discount.

2.5. P2P evaluation and implementation

After conducting the P2P trading task, participants reported whether they would prefer to be able to set prices manually or would prefer prices to be set automatically. Those participants who indicated that they would prefer to set prices (i.e., 63.6%), were additionally asked whether they would prefer to set prices for each actor individually or to set one price that applies to all actors. 84.1% preferred the option to set different selling and buying prices for each group of actors taking part in the electricity community over the option that the same selling and buying prices are applied across all actors. Moreover, participants reported how attractive they find an electricity community on a scale from 1 – *not attractive at all* to 7 – *very attractive*. On average, participation in an electricity community similar to the one presented in the present research was rated as rather attractive ($M = 4.85$, $SD = 1.74$).

3. Data analysis

The analysis of main research questions followed the definition in the preregistration report. In order to answer *Research Question 1*, a linear model was computed with the two within-subjects factors *trading condition* (buying vs. selling) and *trading actor* (i.e., schools and hospitals, small businesses, multinational companies, low-income households, friends and family, direct neighbours). Set trading prices served as dependent variable. Trading price was assessed as the difference from the default energy price and could range from −5 to +5 pence/kWh [€Cent/kWh]. It was controlled for *nation* (UK vs. Germany) and *visibility of trading decisions* (public vs. private) as well as for random effects on the subject level. To examine *Research Questions 2 and 3* buying and selling decisions were analysed separately and the interaction terms of the between-subjects factors *visibility* (public vs. private) and *nation* (UK vs. Germany) were added to the model. This analysis tested the preregistered hypothesis "In the publicly visible condition, participants will set higher buy prices and lower sell prices compared to in the private condition".

To examine *Research Question 4*, buying and selling decisions were again examined separately and political orientation, climate change beliefs, place attachment as well as their interaction terms with trading actor were added to the model. Finally, effects of trust towards the actors on set trading prices was examined, while controlling for political orientation, climate change beliefs, and place attachment. The independent variables were z-standardized prior to the analyses. The results of the analysis are presented in the following section.

4. Results

4.1. Differences in energy trading price preferences depending on P2P actor (Research Question 1)

As illustrated in Fig. 2, the variation in decisions was greater in the selling condition compared to the buying condition. Overall, however, there was no statistically significant difference between set selling and buying prices ($F(1, 9691) = 1.55$, $p = .212$). Importantly, participants set different trading prices depending on the involved actor ($F(1, 9691) = 178.29$, $p < .001$). This actor-specific price setting was moreover subject to the trading condition ($F(1, 9691) = 368.05$, $p < .001$),

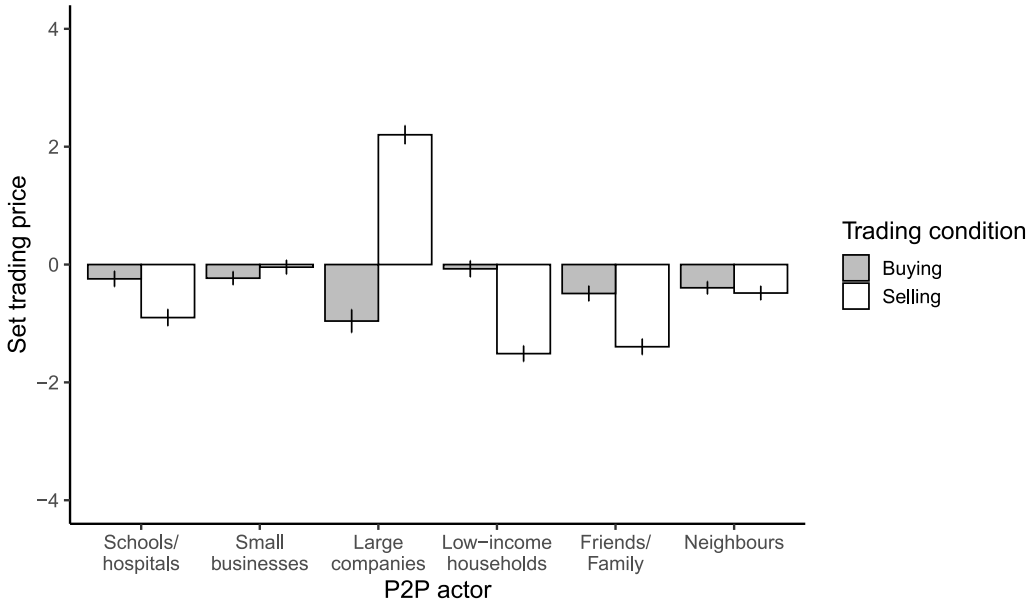

Fig. 2. Set trading prices as a function of trading actor and trading condition (selling vs. buying). Values on the y-axis refer to differences in €/Cent (German sample) and pence (UK sample) from the default electricity price. That is, in the selling condition, positive values reflect that participants asked for a price premium and negative values reflect that participants offered a discount. In the buying condition, positive values reflect that participants offered a price premium and negative values reflect that participants asked for a discount. Error bars depict 95% confidence intervals. P2P actor = Trading actor in the peer-to-peer community.

pointing to three different trading patterns: participants either set similar prices in the selling and buying condition (*tit-for-tat pricing*), offered discounts in the selling condition, but did not request similar discounts in the buying condition (*altruistic pricing*), or requested discounts in the buying condition but asked for price premium in the selling condition (*noncooperative pricing*). A tit-for-tat trading pattern was more likely when participants traded with neighbours ($\chi^2(1) = 1.08$, $p = .299$) and small businesses ($\chi^2(1) = 4.837$, $p = .056$). An altruistic trading pattern was more likely when they traded with friends and family ($\chi^2(1) = 112.58$, $p < .001$), schools and hospitals ($\chi^2(1) = 59.56$, $p < .001$), and low-income households ($\chi 2(1) = 285.67$, $p < .001$). A noncooperative trading patterns was more likely when participants traded with large multinational companies ($\chi^2(1) = 59.56$, $p < .001$). See Supplementary Tables 1-2 for complete results.

4.2. *Differences in energy trading price preferences depending on visibility and nation (Research Questions 2–3)*

On average, across the UK and Germany there was no significant difference in buying or selling price preferences between the private and public visibility conditions, meaning that our preregistered hypothesis was not supported. However, there was a difference in the effect of

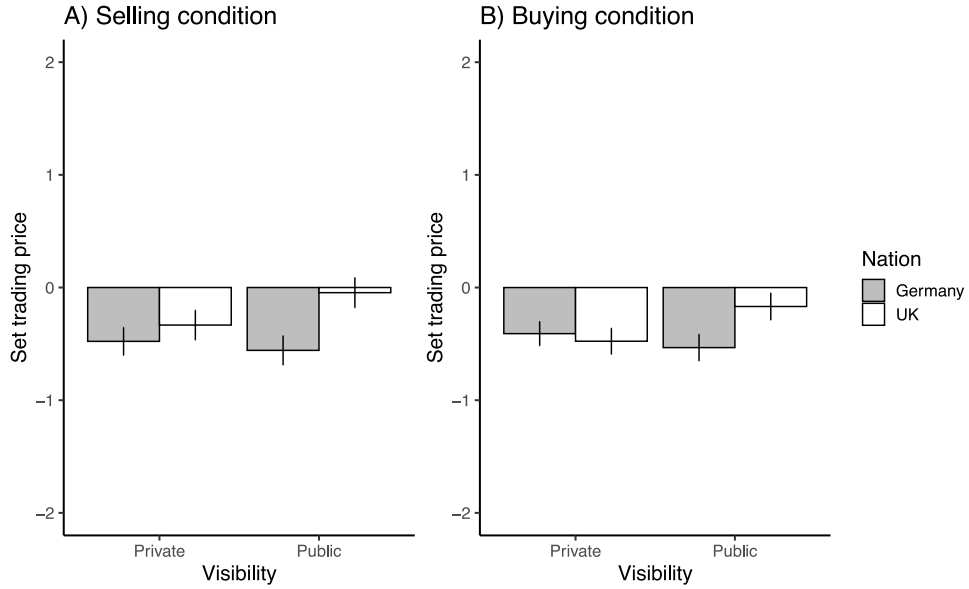

Fig. 3. Set selling prices A) and buying prices B) as a function of nation and visibility of trading decisions (private vs. public). Values on the y-axis refer to differences in €/Cent (German sample) and pence (UK sample) from the default electricity price. Error bars depict 95% confidence intervals. Visibility = Experimental condition of visibility of trading decisions.

visibility between the UK and Germany. UK participants set overall higher prices compared to German participants in the selling condition ($F(1, 881) = 12.53$, $p < .001$). As illustrated in Fig. 3a, this effect was subject to the visibility of trading choices ($F(1, 881) = 3.93$, $p = .048$) in that set selling prices did not differ between nations when they were made privately ($\chi 2(1) = 1.223$, $p = .269$) but significantly differed between nations when they were made in public ($\chi 2(1) = 15.12$, $p < .001$). Specifically, UK participants offered smaller price discounts than German participants when their trading decisions were publicly visible. This effect was independent of the trading actor ($F(1, 4405) = 1.97$, $p =$ 080). See Supplementary Tables 3-4 for complete results.

A similar pattern was observed in the buying condition in which national differences were likewise subject to the visibility of trading decisions ($F(1, 881) = 5.61$, $p = .018$). As illustrated in Fig. 3b, set buying prices did not differ between nations when they were made privately ($\chi 2(1) = 0.27$, $p = .600$) but significantly differed between nations when they were publicly visible ($\chi 2(1) = 7.93$, $p = .010$). Specifically, UK participants asked for smaller price discounts than German participants when their trading decisions were publicly visible. This effect was independent of the trading actor ($F(1, 4405) = 0.352$, $p =$ .881). See Supplementary Tables 5-6 for complete model results. In addition, it was indicated that UK and German participants differ in the extent to which they set buying prices depending on trading actor ($F(1, 4405) = 3.242$, $p = .006$). Post-doc tests however did not reveal national differences for any of the six actors ($\chi 2(1) \leq 6.30$, $p \geq .072$). See Supplementary Table 7 for complete model results.

4.3. Influence of psychological variables on set trading prices (Research Question 4)

4.3.1. Individual trait differences

Participants' political orientation, place attachment, and climate change beliefs impacted their set trading prices as a function of the trading actor at hand. Whereas there was no main effect of *political orientation* ($F(1, 870) = 3.38$, $p = .066$), participants' political orientation impacted selling decisions depending on the involved trading actor ($F(5, 4350) = 12.82$, $p < .001$). Please refer to Supplementary Table 8 for complete results. In line with the value foundations of left and right political orientations, participants with a more pronounced left political orientation were more likely to demand higher selling prices from multinational companies ($Est_B = -0.29$, $t = -3.38$, 95% CI[−0.46,-0.12], $p < .001$) and were more likely to grant higher discounts to low-income households ($Est_B = 0.34$, $t = 4.74$, 95% CI[0.20,0.49], $p < .001$) compared to participants with a more pronounced right orientation (see Fig. 4A). In the selling condition, a more pronounced left orientation was related to higher discounts for friends and family ($Est_B = 0.20$, $t = 2.70$, 95% CI[0.05,0.34], $p = .007$), whereas political orientation did not influence selling decisions with small businesses, schools and hospitals, and neighbours (See Supplementary Tables 9-14 for complete selling results for each actor). Moreover, participants' political orientation impacted buying decisions depending on the trading actor at hand ($F(5, 4350) = 2.85$, $p = .014$). Please refer to Supplementary Table 15 for complete results. In line with the results in the selling condition, participants with a more pronounced left orientation were more willing to pay more for electricity from low income households ($Est_B = -0.20$, $t = -2.69$, 95% CI[-0.35,-0.05], $p = .007$; see Fig. 4B). See Supplementary Tables 16-21 for complete buying results for each actor.

Place attachment influenced selling decisions as a function of involved trading actor in that participants with stronger place attachment were more likely to grant discounts to local stakeholders, including neighbours ($Est_B = -0.29$, $t = -4.75$, 95% CI[-0.41, −0.17], $p < .001$), hospitals and schools ($Est_B = -0.20$, $t = -2.69$, 95% CI[-0.34,-0.05], $p =$ .007), small businesses ($Est_B = -0.14$, $t = -2.31$, 95% CI[-0.27,-0.02], $p =$ .021), and low income households ($Est_B = -0.14$, $t = -2.05$, 95% CI [-0.27,-0.01], $p = .041$). In contrast, place attachment did not influence buying conditions as neither a main effect ($F(1, 870) = 1.03$, $p =$

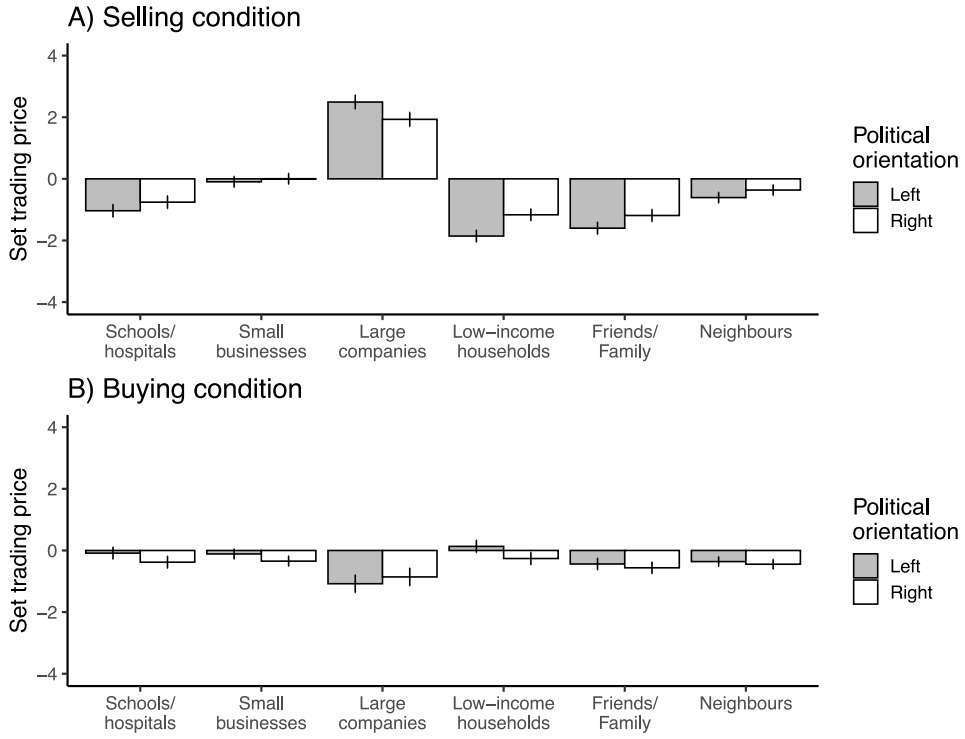

Fig. 4. Set selling prices A) and buying prices B) as a function of trading actor and self-reported political orientation. Values on the y-axis refer to differences in €/Cent (German sample) and pence (UK sample) from the default electricity price. Predicted prices individually calculated for each actor are presented. Left and right political orientation refer to -1SD and +1SD from the mean, respectively. Error bars depict 95% confidence intervals.

.311) nor an interaction with actor ($F(5, 4350) = 1.24$, $p = .288$) could have been observed. See Supplementary Material for the influence of place attachment for each actor separately in the selling (Supplementary Tables 9-14) and buying condition (Supplementary Tables 16-21).

Climate change beliefs impacted trading decisions as a function of trading actor ($F(1, 870) = 2.90$, $p = .013$). In line with research illustrating that environmental and altruistic motives are strongly interlinked [53,54], participants with more pronounced climate change beliefs were more likely to grant selling discounts for schools and hospitals ($Est_B = 0.18$, $t = -2.26$, 95% CI[-0.338,-0.023], $p = .024$) and low income households ($Est_B = -0.15$, $t = -2.03$, 95% CI[-0.30, −0.00], $p = .043$). Finally, climate change beliefs impacted buying decisions as a function of actor ($F(5, 4350) = 4.72$, $p < .001$) in that participants with more pronounced climate change beliefs offered lower buying prices to large multinational companies compared to participants with less pronounced climate change beliefs ($Est_B = -0.28$, $t = -2.49$, 95% CI[-0.49, -0.06], $p = .013$). See Supplementary Material for the influence of climate change belief for each actor separately in the selling (Supplementary Tables 9-14) and buying condition (Supplementary Tables 16-21).

4.3.2. Individual differences in actor-specific trust

As illustrated in Fig. 5, reported trust significantly varied across actors ($F(5, 4405) = 612.37$, $p < .001$). Except for neighbours and small businesses, reported trust levels significantly differed between all actors. See Supplementary Table 22 for all differences.

Analysis of the impact of trust on selling preferences revealed that higher trust in a given trading actor resulted in lower set selling prices ($F(1, 5136) = 197.38$, $p < .001$). As illustrated in Fig. 6A, the influence of trust on selling prices varied between trading actors ($F(1, 4559) = 3.56$, $p = .003$). Trust most strongly impacted selling decisions when participants traded with friends and family ($Est_B = -0.65$, $t = -7.06$, 95% CI [-0.84,-0.47], $p < .001$) and this influence was stronger compared to when participants traded with neighbours ($Est_B = 0.22$, $t = 2.26$, 95% CI [0.03,0.41], $p = .024$) and low-income households ($Est_B = 0.24$, $t = -7.06$, 95% CI[0.05,0.44], $p = .013$) and marginally stronger compared to small business ($Est_B = 0.19$, $t = 1.89$, 95% CI[-0.01,0.39], $p = .059$), but not compared to multinational businesses $Est_B = -0.05$, $t = -0.50$, 95% CI[-0.24,0.14], $p = .618$) and schools or hospitals $Est_B = 0.10$, $t = 0.10$, 95% CI[-0.09,0.29], $p = .319$). See Supplementary Tables 23-28 for the influence of trust on set selling prices for each actor separately.

Trust also impacted buying decisions ($F(1, 5204) = 23.15$, $p < .001$) and the influence of trust on buying decisions varied between actors ($F(1, 4612) = 3.15$, $p = .008$). As illustrated in Fig. 6B, trust most strongly impacted buying decisions when participants traded with multinational companies ($Est_B = 0.46$, $t = 4.21$, 95% CI[0.24 0.67], $p < .001$) and this influence was stronger compared to when participants traded with small business ($Est_B = -0.30$, $t = -2.90$, 95% CI[-0.50,-0.10], $p = .004$), low-income families ($Est_B = -0.26$, $t = -2.71$, 95% CI[-0.45, −0.07], $p = .007$), friends and family ($Est_B = -0.32$, $t = -3.07$, 95% CI[-0.53,-0.12], $p = .002$), and neighbours ($Est_B = -0.31$, $t = -3.21$, 95% CI[-0.50,-0.12], $p = .001$) and marginally stronger compared to hospitals and schools ($Est_B = -0.18$, $t = -1.86$, 95% CI[-0.37,0.01], $p = .062$). See Supplementary Tables 29-34 for the influence of trust on set buying prices for each actor separately. The interpretation of these and the previous results are discussed in the next section.

5. Discussion

The present multinational, preregistered research investigates P2P trading decisions and the underlying factors in a prosumer-centred electricity community with various private and non-private actors. Our results show that people do indeed set different trading price preferences with different community actors. Most of this variance stems from changes in the selling price that people choose to set, with a combination of relatively deep discounts and steep premiums. Whether trading preferences were made in private or were publicly visible did not impact trading decisions overall. There was, however, variation between countries, with UK participants offering and asking for smaller discounts when decisions were made public. Finally, our findings demonstrate that interindividual differences in political orientation, place attachment and climate change beliefs as well as differences in actor-specific trust are underlying drivers of trading decisions.

This section first discusses the main limitations of this study and the generalisability of the findings. Following the interpretation of the results, the implications for policy, practice and future research will be discussed.

5.1. Limitations

The main limitation of this study is the hypothetical nature of the scenario. Results based on stated preferences may vary from real-world

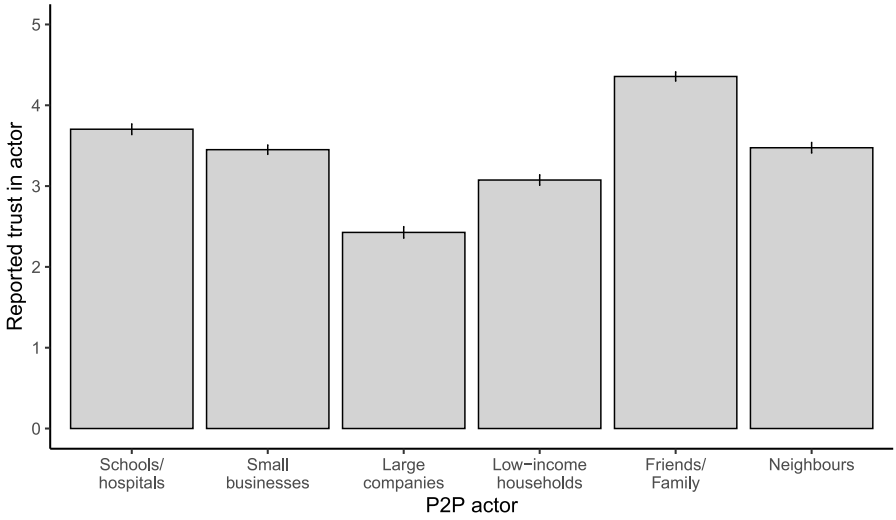

Fig. 5. Reported trust in the involved actors in the P2P community. Higher values on the y-axis refer to higher reported trust. All differences, except for the difference between neighbours and small businesses are statistically significant ($p < .001$). Error bars depict 95% confidence intervals. P2P actor = Trading actor in the peer-to-peer community.

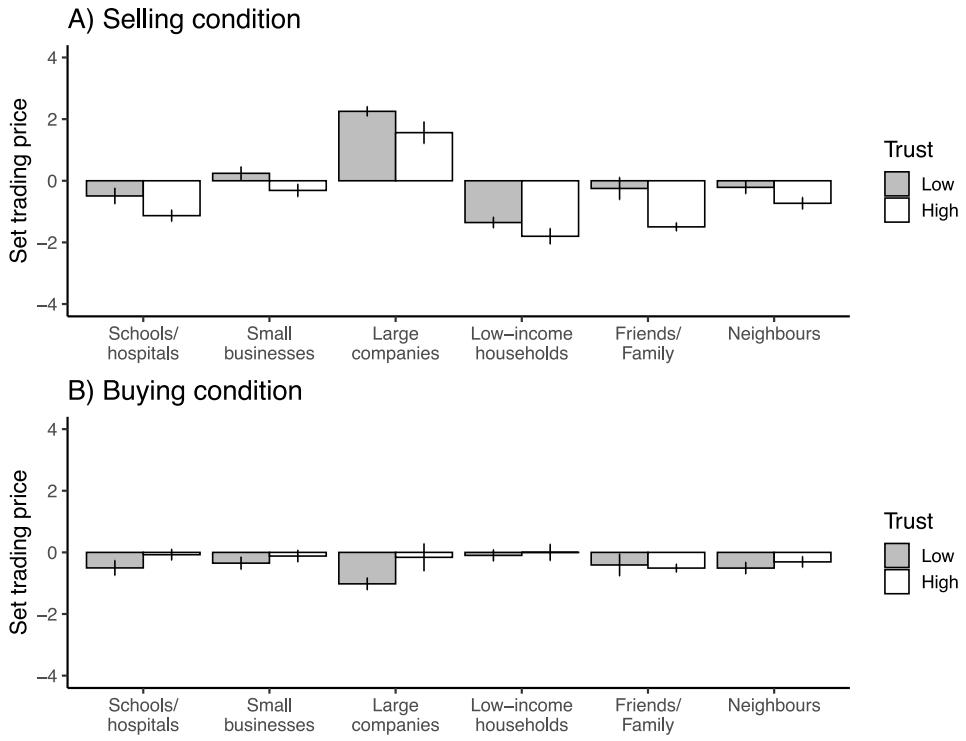

Fig. 6. Set selling prices A) and buying prices B) as a function of actor and reported trust towards a given actor. Values on the y-axis refer to differences in €/Cent (German sample) and pence (UK sample) from the default electricity price. Trust was z-standardized across all actors before the analysis. Low and high trust refer to -1SD and +1SD from the mean, respectively. Error bars depict 95% confidence intervals.

behaviours (but see also recent findings on the ecological validity of stated preferences [63,64]). This could be for a range of reasons, including unfamiliarity with the scenario, social desirability bias [65], and influencing factors in real life that were not controlled for in the present study. Various measures were applied to increase the ecological validity of the price-setting scenario. The measures encompass that participants had the opportunity to set default prices that then, in turn, could be administered by a trading algorithm in everyday life. As discussed recently, this default setting could be a realistic option to implement individual P2P decision preferences in future P2P communities by concomitantly reducing user workload [13].

Despite the benefits of our cross-national comparison, a further limitation attaches to the conduct of the study in two countries simultaneously. This required administering the survey in two languages, and using two different currencies. Any influence of currency could come as a result of two factors – the incremental value of one Euro Cent compared to one pence (the former is worth approximately 90% of the latter), and the relative impact of a discount or premium on the average unit price in Germany or the UK [61,62]. Because of the higher price of electricity in Germany (approximately twice as high as in the UK), the relative impact of adding or subtracting one Euro Cent in Germany compared to one pence in the UK is lower. However, given the broadly similar results obtained in the two countries, it is unlikely that relative prices (compared to absolute prices) had strong impacts on the findings.

5.2. Generalisability

While conducting this study simultaneously in two countries introduced the challenges highlighted above, it also brought with it benefits for generalisability. The reproduction of many of the findings in two completely independent samples in different national contexts suggests that the findings are likely also to be relevant in other countries with similar societal and energy system characteristics. However, future research should systematically examine differences in trading decisions and strategies across nations, ideally encompassing multiple nations in order to analyse the impact of nation-level variables on individual decision-making.

Another important consideration for the generalisability of this study was its conduct in the midst of the Covid-19 pandemic [60]. At the time of study deployment in December 2020, both the UK and Germany were experiencing regional restrictions on citizens' freedom to move and associate. The pandemic has also brought with it increasing contact or even reliance on neighbours by some for services such as collecting food and medicines. Such considerations could have some bearing on the extent to which people believed altruistic behaviour was merited. These factors should be taken as important context in considering how far the results reported here might be applicable in the years to come. See Supplementary Note 2 for information on perceived effects of the pandemic reported in our samples.

5.3. Interpretation

There are a range of possible explanations for the larger willingness to offer discounts on selling prices and to offer premiums on buying prices. Given the typical size of domestic solar installations, the quantity of excess power sold is likely to be relatively small compared to the amount which is purchased. Participants who considered this may therefore have been more willing to show movement in their selling prices, expecting the absolute impact of this to be relatively small. It may also have been connected with loss aversion, where people place greater value on losses than gains of an equivalent magnitude [66]. Because the decision task was framed around excess generation, discounting sale of this may be framed as a smaller gain, rather than a loss – as would be the case for paying more for power.

Our analysis points to three different trading strategies that participants applied, depending on the trading actor at hand. Specifically, the

findings revealed *tit-for-tat* pricing with neighbours and local small businesses, *altruistic* pricing with friends and family, local schools and hospitals, and low-income households, and *noncooperative* pricing for large companies. The analysis further showed that trust was a strong underlying driver of altruistic trading patterns, but of less relevance for tit-for-tat trading patterns where discounts were relatively low. That is, participants not only reported high levels of trust for friends, family and schools, but also integrated trust appraisals in their decisions to a larger extent when they traded with those groups. Correspondingly, offered discounts were among the highest for those groups. Interindividual differences in trust, however, could not explain altruistic trading with low-income families, who received overall the highest discounts. These findings indicate a difference in operation between altruistic behaviour reflecting an expression and acknowledgement of social ties and altruistic behaviour reflecting perceived need.

Noncooperative trading patterns were further shaped by participants' political orientation in that participants with a more pronounced left political orientation were more likely to charge a higher premium to multinational companies. This trading pattern can be associated with variation in market and system justification beliefs along the left-right political spectrum [49,50]. Specifically, a more pronounced right political orientation has been linked with stronger beliefs that market and economic processes are inherently fair and do not require significant regulations [49]. Demanding relatively lower selling prices from multinational companies aligns with such beliefs. Our findings moreover corroborate research showing that political conservatism is associated with more tolerance for social inequality [67]. In accordance, in our study a more pronounced right political orientation was associated with a lower willingness to offer discounts and to charge a lower premium to low-income households compared to a more pronounced left political orientation.

Participants who expressed more concern about climate change were similarly more likely to offer discounts to low-income households, and public services. This is consistent with previous research linking environmental and altruistic concerns [53,54]. Future research, separating environmental and altruistic interindividual differences can help to disentangle the influence of environmental and altruistic drivers of trading decisions in PCM. Furthermore, higher place attachment was associated with willingness to offer higher discounts to local actors. Such an offer of discount can be interpreted as an affirmation of solidarity with the locality and its residents and services. These findings also broadly accord with work by Georgarakis and colleagues [9] who found that prosumers who were energy cooperative members were less motivated by personal economic gain than non-members in their stated trading preferences.

Our findings do not indicate an overall impact of public visibility of trading preferences on set trading prices. However, this does mask a modest inter-country difference. While in both countries participants set similar buying and selling prices when trading preferences were private, they diverged when preferences were framed as publicly visible. German participants' preferences did not change, but UK participants offered, and requested, smaller discounts when their trading decisions were public. This finding illustrates the importance to consider heterogeneity across contexts and populations in the analysis of human decision-making as well as in the design of decision environments [68]. Making decisions public thus cannot be seen as a universal strategy to stimulate more generous trading prices, but can even result in inverse effects, depending on where the intervention is implemented (see also [69]).

5.4. Implications for policy and future research

The findings suggest that there is potential for modest bill savings for some actors, particularly public services, low-income households, and the friends and family of participating prosumers. These savings are subsidised by the prosumers themselves. This finding has implications for energy justice and may offer new pathways to provide specific groups such as low-income families access to renewable energy at lower prices [7,13,70,71]. However, actor-specific price definitions also increase the risk that discriminatory pricing practices arise, as has been observed for factors such as race and ethnicity in the P2P accommodation service Airbnb [72]. These potential risks and benefits for energy justice need to be examined in future research in order to develop PCM that allow for affordable clean energy access without discriminating against certain groups.

Our findings indicate these savings would be more marked in areas where there are more politically left-leaning citizens, greater place attachment, or more concern about climate change. This suggests the ability to save money as a consumer in P2P energy trading communities and other PCM could be driven by who you know and the ideological makeup of the place you live. However, the scale of discounts observed, combined with the fact that PCM transactions will only account for a proportion of electricity consumption, means bill impacts are likely to be modest. However, it is possible that changes in the ways that actors are grouped and framed could amplify these impacts, as we observed for trading preference visibility in the UK.

Policymakers and regulators will need to balance the desire to promote innovation in support of net-zero carbon ambitions against the risk of amplifying inequalities [71]. Our results show a willingness to subsidise services and households in need. But policymakers must also consider the extent to which it is desirable for such subsidies to be delivered via the means of electricity bills at the discretion of individual prosumers, rather than socialised across all bill- or tax-payers. This mirrors debates around the relative merits of charity and taxation – the former providing donors an option to support causes of their choice, while risking that less visible underlying causes go underfunded [73].

Finally, the findings suggest a number of avenues for future research. In common with most stated preference-based research, it will be important to observe the extent to which our findings are replicated in real-world trials. Our findings may also usefully inform user-centred PCM community modelling that attempts to integrate human decision-making preferences to make more accurate predictions of community performance [13]. The found inter-country differences reinforce the importance of recognising contextual heterogeneity in studies of behaviour [68]. Conducting multi-regional studies in a transparent and consistent ways will help shed light on which outcomes are most robust to contextual differences, and which are more dependent on them. Application of realist approaches to research, which explore "what works, for whom, in what circumstances, how and why?" [74] are likely to be particularly useful.

6. Conclusions

This present study tested whether people set different buying and selling prices with different actor groups in a hypothetical prosumer-centred P2P electricity trading scheme. The results based on German and UK samples revealed three distinct trading decision strategies that individuals applied in both countries depending on trading actor: *tit-for-tat*, *noncooperative*, and *altruistic* decision strategies. Most variation in price settings occurred in the level of discount offered on electricity sales to different actors. The biggest discounts were offered to low-income households, and friends and family. This was followed by schools and hospitals, and neighbours. A substantial premium was charged to multinational companies. Variation in buying price was relatively limited, with no actor offered a premium above the average electricity price, and a substantial discount requested only from larger multinational companies. The impact of psychological variables such as trust differed, depending on the involved trading actor. Finally, making trading preferences publicly visible impacted decisions as a function of national context, with UK participants offering and asking for smaller discounts when their decisions were public. Taken together, the findings illustrate the need to consider contextual and psychological factors in the design of prosumer-centred electricity markets in order to exploit the

full potential of such collective energy systems.

Author contributions

Hahnel, U.J.J: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. Fell M.J: Conceptualization, Funding acquisition, Investigation, Methodology, Writing – original draft, Writing – review & editing

Data availability statement

The data that support the findings of this study, along with the analysis code, are openly available in the Open Science Framework (OSF) at https://osf.io/cau9v/?view_only=d92aaa2c8a9540bda8b9361ea75f98e6.

Further details relevant to the transparency, reproducibility and quality of reporting of this study are presented in Supplementary Table 35 [75].

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We gratefully acknowledge support from UK Research and Innovation through the Centre for Research into Energy Demand Solutions, grant reference number EP/R035288/1. The funding sources had no involvement in the preparation of the article, in the study design, the collection, analysis and interpretation of data, nor in the writing of the manuscript. We are grateful to Laura Pagel for her support in developing the study material and in collecting the cross-national data.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.rser.2022.112419.

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