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Essays on consumers in a changing energy system

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Summary

This dissertation investigates the role of households and their willingness to take part in an energy system. As the energy system becomes more decentralized, the traditional electricity value chain alters into a network in which the roles regarding production, consumption, and distribution are newly defined. This transition makes it possible for consumers to involve themselves more actively, and households can assume novel functions such as producers of electricity. This is especially pertinent in Germany where a rising share of the electricity is being generated from renewable sources. The dissertation contributes to the understanding of household roles and consumer involvement in the energy system, in order to help design and implement a functional future system. The analysis is based on a consumer perspective, focusing on local and regional power generation and storage as well as electricity tariffs. Two online surveys were conducted in Germany: one investigating changing involvement of consumers by using a sample of both the general population and of adopters of a renewable energy system (*Chapters 3.1* and *3.3*), and another researching the role of prosumers by sampling owners of a photovoltaic system (*Chapter 3.2*). *Chapter 3.1* investigates the willingness to participate in community energy projects by examining the role of trust, social norms and community identity. *Chapter 3.2* analyzes consumer preferences and willingness to pay for battery storage systems by using a choice experiment. Finally, *Chapter 3.3* applies the same method to estimate preferences for electricity tariffs. This analysis centers on spatial aspects of the energy system, i.e. the proximity of generation and providers. The findings show potential for community-based energy solutions, new residential and joint-usage battery storage concepts, and electricity tariffs which provide regionally generated electricity from renewable sources. This dissertation contributes to the understanding of consumer attitudes and preferences, as well as the changing relationships in the energy system, thereby helping advance the transition towards renewable energies. The implications are relevant for academia, companies operating in the energy sector, and policy-makers alike.

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List of Abbreviations and Acronyms

CBS	Community battery storage system
EIA	U.S. Energy Information Administration
Energiewende	Energy transition in Germany
IIA	Independence of irrelevant alternatives
iid	Independently and identically distributed
kWh	Kilowatt hour
NIMBY	Not-in-my-backyard
OECD	Organisation for Economic Co-operation and Development
PV	Photovoltaics
RBS	Residential battery storage system
SD	Standard deviation
TWh	Terawatt hour

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1. Introduction

1.1. Towards a more sustainable electricity system

In the context of climate change and growing debates around sustainability, the energy – and more specifically electricity – sector is seen to be a major contributor to the increase in greenhouse gas emissions (Agnew & Dargusch, 2015; Bruckner et al., 2014). Globally, it is estimated that around 66% of these emissions are related to energy generation and consumption (IEA, 2015, 2016a). This is due to the continued reliance on fossil fuels which still dominate energy generation, with as much as 58% of electricity being generated by fossil fuels in the OECD countries (IEA, 2016c). The problem is compounded by demand for energy more than doubling over the last 45 years (IEA, 2016c). Looking ahead, projections estimate a further rise in total energy consumption by around 48% and an increase in global net electricity generation by 69% from 2012 to 2040 (EIA, 2016).

While the electricity sector is seen as a major culprit in damaging the environment, many commentators have argued that energy systems could yet play a key role in creating a more sustainable world (Agnew & Dargusch, 2015; De Sisternes, Jenkins, & Botterud, 2016; Victor et al., 2014). Clean energy is a key goal for sustainable development (United Nations, 2015; Griggs et al., 2013).[1] To reach a more environmentally and socially sound society and economy, sustainable consumption and production patterns must be made the norm, with policy-makers and businesses being required to encourage more sustainable individual and organizational behavior (George, Schillebeeckx, & Liak, 2015; Prothero et al., 2011; see also United Nations, 2016; United Nations Framework on Climate Change, 2015).

Developing and mainstreaming renewable energies is seen as one solution to a more sustainable energy system (Bruckner et al., 2014). Many governments around the world have begun to action this through the setting of emission reduction targets and the introduction of deployment policies for diffusing renewable energy technologies (United Nations Framework on Climate Change, 2015). Furthermore, the European Union has set *20-20-20* targets to have the share of renewable energies in the final energy consumption reach 20%, increase energy efficiency by 20%, and cut greenhouse gas emissions by 20% by the year 2020, when compared to 1990 (European

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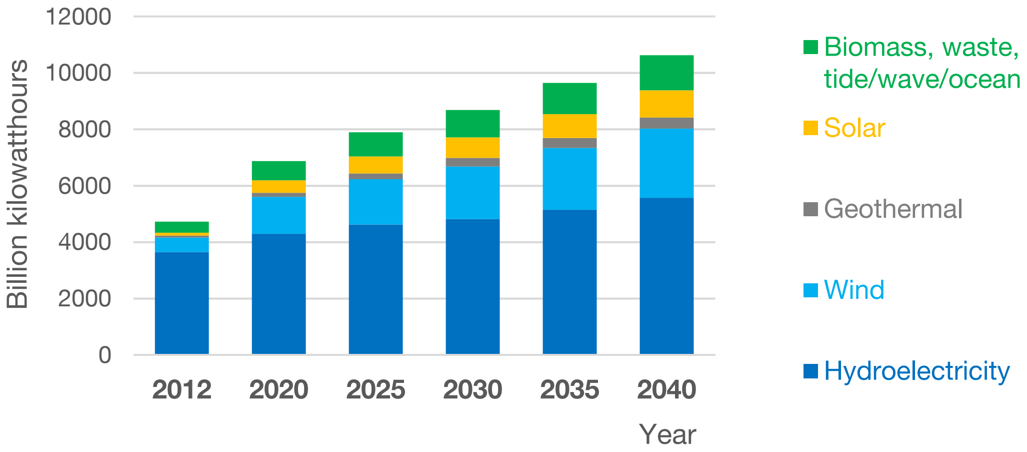
[1] Sustainable development is defined as *development that meets the needs of the present without compromising the ability of future generations to meet their own needs* (World Commission on Environment and Development, 1987). The concept of sustainability comprises the triple bottom-line of social, environmental, and economic objectives (see Allison et al., 2016; Pope, Annandale, & Morrison-Saunders, 2004; United Nations, 2015).

Commission, 2010). Globally, energy companies have invested in decentralized renewable energy technologies such as photovoltaic (PV) systems (Sioshansi, 2016). This has, for instance, helped to increase the proportion of electricity being generated from renewable sources from 17.5 to 33.1% in European OECD countries during the period 1990 to 2015 (IEA, 2016a). As shown in Figure 1, renewables are expected to show the fastest growth relative to other electricity sources with 2.9% p.a. from 2012 to 2040 (EIA, 2016).

Figure 1: Forecast of global net renewable electricity generation by energy source



Source: Own illustration based on U.S. Energy Information Administration (EIA) (2016)

Tying all these threads together, the energy system is *on the cusp of unprecedented transformation* (Agnew & Dargusch, 2015, p. 316). Rapid change and transformation characterize the electricity system (Araújo, 2014; Römer, Reichhart, Kranz, & Picot, 2012; Verbong, Verkade, Verhees, Huijben, & Höffken, 2016), with Wainstein and Bumpus (2016, p. 572) arguing that a *technological and systemic revolution* is needed to facilitate the integration of renewable energies and build a more sustainable system. In the future, the form and design of the electricity system might differ substantially from its current implementation (Khalilpour & Vassallo, 2015; Peças Lopes, Hatziargyriou, Mutale, Djapic, & Jenkins, 2007), being characterized by more decentralized energy systems and a focus on recruiting the residential sector and households to help tackle climate change (see Druckman & Jackson, 2016; Stern, Janda, et al., 2016; Wilson, Tyedmers, & Spinney, 2013).

Changes in the energy system can already be witnessed in the falling prices of PV systems (75% since 2006) (Wirth, 2016; see also IEA, 2016c) and onshore wind technologies (35%) (IEA, 2016d), contributing to their further diffusion. Moreover, the costs of battery storage systems in Germany have decreased by 39% since 2013 (Kairies et al., 2016). While such developments have accelerated the transition, particularly on the household side (see Khalilpour & Vassallo, 2015), distributed generation is reshaping the energy system, from being centralized – the traditional system with large power plants (see Debizet, Tabourdeau, Gauthier, & Menanteau, 2016) – to decentralized, with more spatially distributed small-scale generation facilities (Jenkins & Pérez-Arriaga, 2017). In such an infrastructure, storage technologies and demand response are of central importance (Akorede, Hizam, & Pouresmaeil, 2010; Chicco & Mancarella, 2009). Most noteworthy is the more active role of consumers and new players in the market (Wainstein & Bumpus, 2016). Renewable energy technologies and battery systems allow individuals to generate and store electricity locally: on their own or by participating in collaborative projects. The energy system is being further transformed by digitalization as well as new forms of collaboration and business models, such as community energy projects, non-ownership concepts, peer-to-peer energy and tenant energy solutions (e.g., Verbong et al., 2016; Wainstein & Bumpus, 2016). Such developments change the way we generate and use electricity and have implications not only for businesses, but for society and the energy system as a whole.

Given their socio-technical nature (see Markard, Raven, & Truffer, 2012), it may be unsurprising that changing energy systems have created more opportunities for citizens to directly engage and participate in various roles, not only as consumers, but also as producers, investors, and societal actors (see Schot, Kanger, & Verbong, 2016).[2] Moreover, decentralized and integrated approaches have led to less spatial distance – and more proximity – between end-users and the energy system (Koirala, Koliou, Friege, Hakvoort, & Herder, 2016). Wainstein and Bumpus (2016) highlight the new routes for citizen participation: bottom-up energy and peer-to-peer business models. Some writers even see a *consumer-led disruption* (Agnew & Dargusch, 2015, p. 318) of the centralized energy system. Hence, consumers are expected to become active participants or key players in the future energy system (Goulden, Bedwell, Rennick-Egglestone, Rodden, & Spence, 2014; Verbong et al., 2016).

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[2] Similarly to Geels (2004), Markard and Hoffmann (2016, p. 64) state that socio-technical systems consist *of different elements, which include actors (individuals, firms and other organizations), institutional structures (societal norms, technology standards, regulations, user practices, culture, collective expectations etc.), technologies and resources (e.g. knowledge, human and financial capital, natural resources).* In terms of the energy system, the socio-technical system consists, hence, not only of generation sites and grid infrastructure, but of all the elements connected to the system (Goldthau & Sovacool, 2012).

Commentators foresee a *radical technological, environmental and economic upgrade of the old system* (Verbong, Beemsterboer, & Sengers, 2013, p. 118). Germany, Denmark, and the USA are marked as being particularly forthcoming in transforming their energy systems (Araújo, 2014). Germany set ambitious objectives to transform its national energy system by focusing on renewable energies (BMWi, 2015; Schreurs, 2016), with the share of renewable sources covering electricity consumption almost a third (AG Energiebilanzen, 2016). On both the supply and demand sides, there are challenges to reaching the policy targets, and new solutions to generate, distribute, store and use energy from renewable sources more efficiently are needed. This transformation represents a shift towards a decentralized system with opportunities for household involvement. Citizens and households are a key pillar in this transition in Germany (J. Mattes, Huber, & Koehrsen, 2015). It is therefore crucial to understand German consumers and their attitudes and preferences regarding electricity consumption and issues in order to create a more sustainable energy system on a national scale. This, in turn, can provide valuable insights for other countries looking to make the same transformation.

1.2. Research context

Individuals and households contribute substantially to carbon emissions and are a key leverage for a more sustainable energy system. Hence, understanding their energy consumption and behavior is vital (Schot et al., 2016). Various scholars have recently emphasized the importance of households and consumer behavior in the context of changing energy systems and sustainable development (Sintov &

Schultz, 2015; Steg, 2016; Steg, Perlaviciute, & van der Werff, 2015; Stern, Janda, et al., 2016; van der Werff, Perlaviciute, & Steg, 2016). In an energy system transforming towards renewable and decentralized energy, the role of households and their energy behavior is further emphasized as they contribute as consumers but also fulfil newer roles such as producers or investors.[3] This can be understood as a form of consumer empowerment, and the development has been taken to be a source of social innovation, particularly with respect to community energy (see BMUB, 2016; Reinsberger, Brudermann, Hatzl, Fleiß, & Posch, 2015).[4]

To reconfigure the energy system, one needs to understand individuals and their preference for, and attitudes towards, various energy-related aspects and behaviors (e.g., Steg et al., 2015). Steg et al. (2015) state that if the goal is to influence energy behavior, understanding consumers' knowledge, motivation and ability to behave in a certain way is essential. According to these authors, such behaviors comprise the adoption of renewable energy technologies, balancing generation and consumption, purchasing a specific electricity tariff, as well as indirect use of energy.

Understanding consumer behavior is pivotal to energy system transformations, since individuals can simultaneously be seen both as

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[3] This dissertation assumes that energy-related decisions are often made by the household and not by individual consumers as such. It takes a consumer research perspective and uses the terms *consumer* and *household* as synonyms.

[4] Social innovations are *alternative practices or new variations of practices which differ substantially from established or mainstream routines* that also *imply structural changes* (Jaeger-Erben, Rückert-John, & Schäfer, 2015, p. 785). They can be new forms of organizations or services that trigger more sustainable consumer behaviors (BMUB, 2016).

contributors to climate change, but also as parts of the solution (Klöckner, 2013). Although decentralization foregrounds the role of individuals and households, studies in the energy field too often focus only on the technical aspects. From fundamental research to radical and disruptive innovations, progress and innovations are needed to further utilize solar energy and storage solutions and to build a sustainable energy system (Boons, Montalvo, Quist, & Wagner, 2013; Lewis, 2016). However, technologies such as PV and battery storage systems must be accepted and adopted by consumers to actually bring about this renewable energy system (Bigerna, Bollino, & Micheli, 2016; Wüstenhagen, Wolsink, & Bürer, 2007). Hence, the focus on consumers is necessary, as it is their acceptance of energy technologies and infrastructure which determines if deployment and adoption is successful (Bidwell, 2016; Huijts, Molin, & Steg, 2012; Komendantova & Battaglini, 2016; Wüstenhagen et al., 2007). For instance, Werff et al. (2016, p. 43) argue that *smart grid technologies and infrastructure will only realise their full potential if people find them acceptable and if they change their behaviour accordingly*. Furthermore, Steg et al. (2015, p. 12) stress that substantial reconfigurations *in human perceptions, preferences and behavior* are needed to transform the energy system. Examining the attitudes and preferences contributes to the understanding of energy behavior and the human side of the energy system. Insights about energy behavior not only help to actively involve citizens in the energy system, they also create larger-scaler opportunities for fostering the transition towards a more sustainable system.

1.3. Research aim and frameworks

1.3.1. Research aim

This dissertation aims to explore the roles of consumers in selected aspects of the German energy system, and, in particular, their preferences and attitudes towards these aspects. In this changing system, households can assume novel roles such as producers of electricity. Understanding these roles and types of consumer involvement in the energy system is necessary for designing and implementing a functional, decentralized energy system. Hence, examining the roles and preferences of households is not only relevant for consumer research, but also for research and practice in the energy and sustainability fields.

The present dissertation strives to improve our understanding of the German energy system by investigating the role of households and how they are willing to take part in this system. It addresses the following research question:

> *What are consumers' attitudes and preferences regarding participation and selected energy-related behaviors in an energy system that is in the process of becoming more decentralized?*

In this way, the study focuses on three important yet relatively unexplored phenomena in the electricity sector that are changing the current energy system – or have the potential to do so. This dissertation only considers the electricity sector when analyzing individuals' energy attitudes and behaviors as consumers, as well as private or collaborative contributors.[5] It hereby centers on Germany, since its national energy transition could be a potential blueprint for transforming an industrialized nation towards having a more decentralized energy system. As the dissertation takes a consumer research perspective, it does not investigate the pros and cons of such an energy system, e.g. in terms of environmental sustainability vs. economic feasibility or implications for the grid.

Examining consumers' attitudes and preferences can help shed light on the systemic changes currently taking place in the energy market, as the linear value chain (see Figure 2) is breaking down and novel relationships are emerging. The decentralization and reconfiguration of the energy system is being driven by the rise of community-based energy projects and the rapidly developing market for battery storage systems, combined with decreasing prices for clean energy technologies. As a consequence, novel approaches to energy supply have sprung up at the local and regional levels. Hence, three specific phenomena will be explored in this dissertation: community-based energy projects, battery storage systems, and regional energy supply.

First, in the context of consumer participation, it is necessary to understand the factors that influence citizens' willingness to engage in energy projects. In particular, community-based energy projects form a pillar of the changing energy system in Germany – although it is still a niche. To help understand the drivers of willingness to participate in

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[5] In general, improvements are needed in all sectors of the energy system, that is, electricity, heating and transportation (see Cucchiella et al., 2016; Pregger, Nitsch, & Naegler, 2013). Moreover, it has to be noted that this dissertation does not analyze behavior change such as, for example, energy saving.

such projects, this dissertation analyzes catalysts for participation. Although social aspects and trust have been found to be relevant in this field (Greenberg, 2014; Thøgersen & Grønhøj, 2010; Walker, Devine-Wright, Hunter, High, & Evans, 2010), a holistic understanding of these drivers is still lacking. This dissertation addresses the particular gap in the understanding of how trust, community identity and social norms have an impact on participation in community-based energy projects.

Second, community-based projects and household engagement in the energy system often focus on energy generation, but the growing market for battery storage systems is enabling on-site balancing of supply and demand and allowing for the further integration of electricity from renewable sources. Although the storage market is dynamic, consumer preferences are still unexplored and there is a lack of knowledge about preferences for residential and community concepts, the provision of grid services, as well as the value of autarky. The dissertation aims to advance the understanding of these aspects.

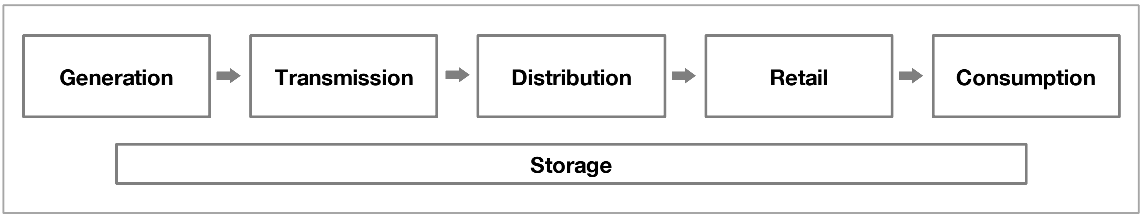
Third, decentralization, with its generation and storage in proximity to end-users, allows for new regional energy supply concepts. Studies on the energy system have often centered on different types of technologies and methods of implementation, while *playing down* the spatial aspects of these approaches (Devine-Wright, 2011b). Hence, there is a lack of research on such regional concepts from a consumer perspective in the energy field. Moreover, regionally generated electricity from renewable sources is seen as a way to support identification with renewable energy sites on the local and regional levels, while fostering their acceptance and the further expansion of renewables (BMWi, 2016b). However, empirical analyses of these claims are still lacking, and, hence, it is necessary to gain a deeper understanding of attitudes and preferences in the context of regional energy supply and tariffs. The dissertation addresses these themes.

1.3.2. Frameworks for the dissertation

This dissertation investigates attitudes and preferences regarding community energy, battery storage systems and regional electricity generation and tariffs. Two frameworks are used to structure the analyses: the value chain of the electricity system and a participation logic.

Traditionally, the electricity system was conceived of as the linear, one-way hierarchy of specific actors involved along the value chain. This value chain stretches from electricity generation, through transportation over the transmission and distribution network, to retail and consumption, with storage at different stages. The value chain is shown in Figure 2 and represents the market logic used in this dissertation. The essays provide insights into three aspects of the electricity system, that are, generating electricity, energy storage, and electricity tariffs.

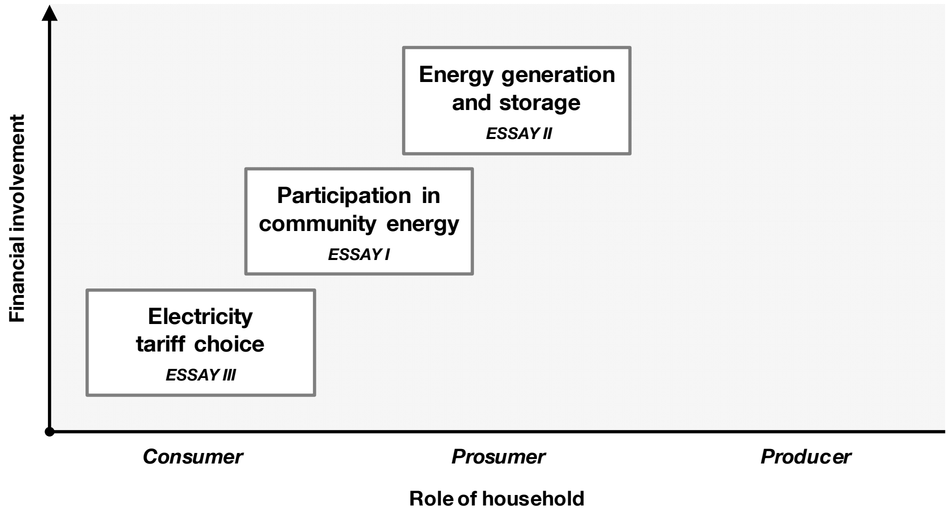
Figure 2: Traditional value chain of the electricity system (market logic)



Source: Own illustration inspired by Richter (2013) and Brunet (2011)

Following the participation logic, individuals have opportunities to directly engage in the energy system. This study analyzes different consumer roles and can be embedded in a participation framework with (a) the role of households in the energy system on the one side – from traditional consumers to producers, with prosumers representing a fused role (see Parag & Sovacool, 2016) – and (b) financial involvement on the other side.[6] The types of participation are different in nature and in terms of consumer involvement, for example choosing a tariff vs. purchasing a battery storage system. Figure 3 illustrates the participation logic and the classification of the three essays.[7]

Figure 3: Classification of the essays in the participation logic



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[6] Arnstein (1969, p. 216) defined citizen participation as *redistribution of power that enables the have-not citizens, presently excluded from the political and economic processes, to be deliberately included in the future* and presented a ladder of participation with eight different forms of participation. Citizen participation is in this dissertation used as a rather broad concept, mainly referring to consumer participation and not political engagement.

[7] The position of the three essays in the figure differs depending on which specific engagement is analyzed, e.g. the volunteering and financial investment in *Essay I*.

1.4. Structure of the dissertation

The remainder of this dissertation is structured as follows: *Chapter 2* provides the background to the energy system and to the specific research focus areas, including the research approach. The analysis of the specific focus areas is presented in three essays *(Chapter 3)*. *Chapter 4* then discusses the key findings and gives recommendations for future research, concluding with managerial and policy implications.

2. Background

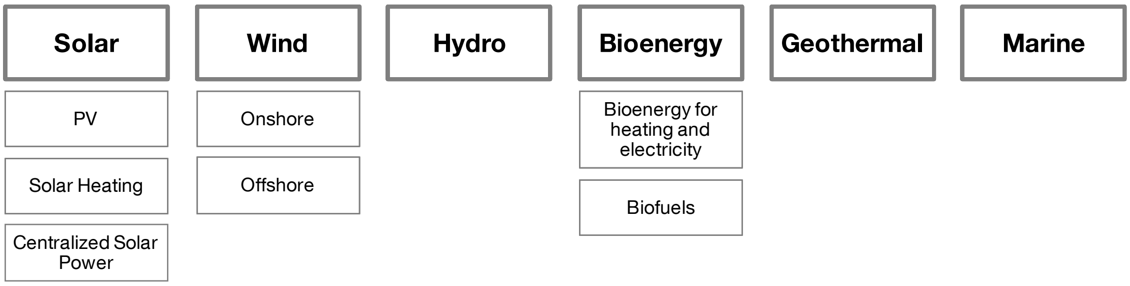
This chapter outlines the conceptual background of the dissertation. *Section 2.1* provides an overview of the German energy system, with a discussion of renewable energies, decentralization and the role of individuals. *Section 2.2* introduces the three focus areas of the study. Finally, *Section 2.3* presents the research approach with some background on attitude and preference measures, an overview of the data collection, and a brief review of existing studies on attitudes and preferences.

2.1. The changing electricity system

2.1.1. Renewable energies and decentralization

Renewable energies are defined as *energy sources that are continually replenished by nature and derived directly from the sun (such as thermal, photo-chemical, and photo-electric), indirectly from the sun (such as wind, hydropower, and photosynthetic energy stored in biomass), or from other natural movements and mechanisms of the environment (such as geothermal and tidal energy)* (Ellabban, Abu-Rub, & Blaabjerg, 2014, p. 749). Figure 4 shows an overview of renewable energy sources.

Figure 4: Overview of renewable energy sources



Source: Own illustration adapted from Ellabban et al. (2014)

Energy from renewable sources is essential to build a cleaner and more sustainable energy system (Sheikh, Kocaoglu, & Lutzenhiser, 2016). Substantial technological improvements have significantly reduced the costs of renewable energy technologies in recent years, including solar systems and wind turbines (Braff, Mueller, & Trancik, 2016; Lewis, 2016; Trancik, 2014). PV systems, for instance, are close to grid parity without subsidies (Hagerman, Jaramillo, & Morgan, 2016; Khalilpour & Vassallo, 2015; Papaefthimiou, Souliotis, & Andriosopoulos, 2016). Wind and PV systems show the highest growth rates among all electricity generation technologies (IEA, 2016d). At the same time, renewable energies are also likely to be supported by the uncertainties surrounding coal and nuclear, for example the future costs, which are expected to be high (Solomon & Karthik, 2011).

While the traditional system was characterized by a centralized infrastructure with generation of non-renewable and nuclear energy, the future will rather be a distributed system relying on renewable energies energy forms (Debizet et al., 2016). The distributed generation from wind and solar power changes the traditional energy system (Verbong et al., 2016). And in many parts of the world the energy system is already transforming (Römer et al., 2012). Decentralized energy – also called distributed energy – can be characterized as small-scale generation (Pepermans, Driesen, Haeseldonckx, Belmans, & D'haeseleer, 2005), and defined as *an electric power source connected directly to the distribution network or on the customer site of the meter* (Ackermann, Andersson, & Söder, 2001, p. 201). The key components of decentralized systems are distributed small-scale generation and storage as well as demand response (Akorede et al., 2010; Chicco & Mancarella, 2009). Energy storage is expected to have a strategic role (Debizet et al., 2016), and the future energy system is therefore likely to be different and smarter than the one we have today (e.g., Khalilpour & Vassallo, 2015).

Much attention has been given to finding a decentralized route to the future energy system (Ackermann et al., 2001; Koirala, Koliou, Friege, Hakvoort, & Herder, 2016; Kubli & Ulli-Beer, 2016; Manfren, Caputo, & Costa, 2011). This represents a transformation from the traditional centralized system to an infrastructure based on small-scale generation at the local level (Halu, Scala, Khiyami, & González, 2016). Scholars have emphasized the positive aspects of decentralized generation, such as environmental benefits and affordability (Halu et al., 2016). Further potential benefits include energy efficiency, positive effects on the grid, improved quality, and community engagement (Koirala et al., 2016; Mendes, Ioakimidis, & Ferrão, 2011; Newcomb, Lacy, Hansen, & Bell, 2013; Rae & Bradley, 2012). However, the optimistic view of decentralization has also been questioned because this system is *more fragmented* (Alanne & Saari, 2006, p. 553), requiring new infrastructure and higher capital costs (Karger & Hennings, 2009). It can also lead to challenges for the distribution network (Passey, Spooner, MacGill, Watt, & Syngellakis, 2011).

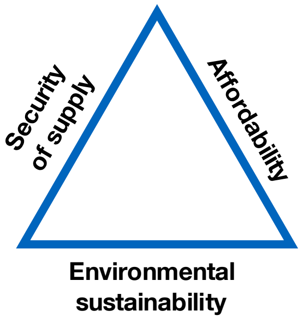
PV systems and wind turbines are considered variable renewable energy technologies because they depend on the availability of wind or sunshine (Stram, 2016). This intermittency – hourly, seasonal, and idiosyncratic – is a key limitation of variable renewable energy sources (Khalilpour & Vassallo, 2015; Stram, 2016), as generation and consumption must be balanced in the energy system (IEA, 2016d). If this is not the case, it would be problematic for the grid (Verbong et al., 2016). Integrating renewable energy sources such as wind and PV is, therefore, constrained by their intermittency and geographic distribution, and by how flexibly the energy system can respond to these factors (IEA, 2016d). The consequence of all this is the need for smart solutions and storage systems, flexibility in generation and demand, auxiliary services, and grid infrastructure that can help to overcome these limitations (IEA, 2016d; Khalilpour & Vassallo, 2015).

2.1.2. The energy transition in Germany

The transformation of the energy system with a focus on renewable energies can particularly be observed in Germany (Brunekreeft, Buchmann, & Meyer, 2016; Markard, Wirth, & Truffer, 2016). Schreurs (2016, p. 114) calls it *one of the most ambitious energy realignments of any major economy in the world.* This transition (also known as *Energiewende*) is at the core of energy policy in Germany (Kemfert, Kunz, & Rosellón, 2015). The term *Energiewende* dates back to the 1980s (Krause, Bossel, & Müller-Reißmann, 1980), and as The

Economist (2012) summarizes, then *became policy in 2000 and sped up after the Fukushima disaster in March 2011.* The policy objective is to design an energy system that incorporates security of supply, affordability, and environmental sustainability (BMWi, 2015).[8] Figure 5 illustrates the objectives of energy policy as the *energy trilemma* (Few, Schmidt, & Gambhir, 2016, p. 7).

Figure 5: The objectives of energy policy



Source: Own illustration based on Erdmann and Zweifel (2010) and Few et al. (2016)

The German government set specific targets to reshape its energy system and focus on renewable energies (Blanchet, 2015). The purpose of this transition is to foster a sustainable reconfiguration of the energy supply, while taking into account economic aspects and stimulating the development of new renewable energy technologies (EEG, 2016). The specific objectives are as follows: To increase the share of electricity generated from renewable sources to 40-45% of gross electricity consumption by 2025, 55-60% by 2035, and at least 80% by 2050 (EEG, 2016). Moreover, nuclear power plants in

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[8] Renn and Marshall (2016), Hake et al. (2015), and Strunz (2014) discuss the background of the German energy transition in detail. Joas et al. (2016) analyze its goals.

Germany will be phased out by 2022 (BMWi, 2014b), and the grid will be reshaped, while taking energy security, affordability and employment effects into account, with an emphasis on energy research (BMWi, 2015). The targets are both quantitative and qualitative in nature. The qualitative targets include ensuring high supply security and energy affordability, to support innovation and the national competitiveness (BMWi, 2015). The energy transition is considered a *regime shift* (Strunz, 2014, p. 154) and an opportunity for innovating Germany not only technologically, but on a broad scale across sectors and technologies (SRU, 2013).

The future system in Germany will build upon renewable energies, in particular wind and PV (Kemfert et al., 2015). In 2015, Germany strongly contributed to the expansion of renewable energies in the OECD countries with an increase in electricity generation from wind by 30.6 TWh and from PV by 2.4 TWh (IEA, 2016b). The share of renewable energy sources in gross electricity consumption increased from 3.2% (1991) and 20.4% (2011) to 31.6% in 2016 (AG Energiebilanzen, 2016), showing that renewable energies can no longer just be considered a niche (Sühlsen & Hisschemöller, 2014).

The energy transition is not only a technological challenge, but also a societal one (see Gawel et al., 2014; Markard et al., 2012; Miller, Richter, & Leary, 2015). The implications of the German transition are, therefore, not limited to businesses, such as power providers and grid operators, but also affect households and the society as a whole (BMWi, 2014a). Schippl and Grunwald (2013) highlight the importance of social effects and issues related to the transforming energy system, for instance distributional justice and conflicts of interests or values (see also Radtke, 2016). This can be understood better by taking into consideration the participation and investment of citizens in decentralized generation, in particular by farmers and cooperatives, who constitute an important building block of the German energy transition (J. Mattes et al., 2015).

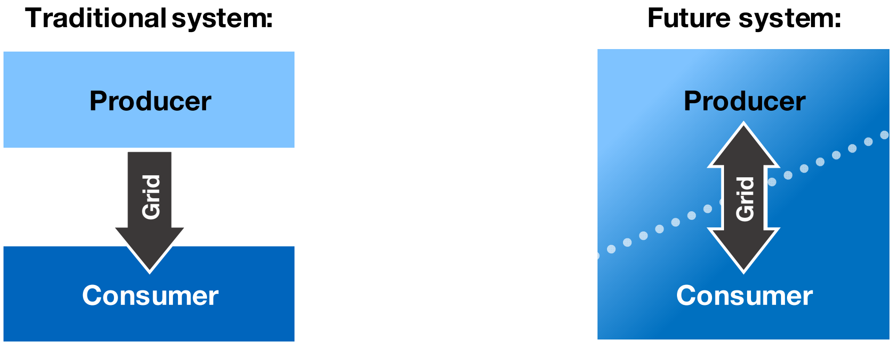
2.1.3. Consumers in the energy system

Nowadays, energy is considered an essential consumer good – Aneke and Wang (2016, p. 351) even call it *the most common consumer good*. Electricity is particularly crucial for individuals and society, since households as well as large parts of the economy rely on it (Negro, Alkemade, & Hekkert, 2012; Stram, 2016). It facilitates many *social practices* (Verbong et al., 2016, p. 35) and is unique in that it is an invisible and abstract product (Fischer, 2007; Grønhøj & Thøgersen, 2011; Hargreavesn, Nye, & Burgess, 2010). The importance of energy consumption for everyday life is significant. Nevertheless, consumers generally express a low interest in energy supply and consumption (Abold, 2011; Bundesnetzagentur/Bundeskartellamt, 2015; Naus, Van Vliet, & Hendriksen, 2015). Pasqualetti (2000) has argued that this might change with the rise of renewable energies.

A historical review of the role of households in the energy system shows that the relationship between energy providers and households is transforming (Naus, Spaargaren, van Vliet, & van der Horst, 2014). While consumers in the energy system had traditionally a passive role, individuals and households today have new opportunities for actively participating and engaging in the energy system (Schot et al., 2016; Shomali & Pinkse, 2016; Verbong et al., 2013, 2016). However, realizing such engagements on an individual or community level is complex (Bigerna et al., 2016; Verbong et al., 2013). Bigerna et al. (2016, p. 406) even argue that *difficulties in consumers' involvement could hinder the change of the energy system, preventing (...) sustainable development.* To reach a more sustainable system, it is necessary to pursue alternative approaches focusing on more than just technology (Verbong et al., 2016).

The future energy system is expected to have a more direct impact on everyday life (Verbong et al., 2013), with households changing from merely passive consumers to more active participants. Transforming the energy system from a one-directional top-down grid to a bi-directional smart grid strengthens the role of households (Houwing, Heijnen, & Bouwmans, 2006; Khalilpour & Vassallo, 2015). Citizens are empowered to actively engage in the system, e.g. as prosumers. Hence, end-users are becoming increasingly important, opening up opportunities for new concepts and business models (Wainstein & Bumpus, 2016). Figure 6 illustrates the changing relationship between generation and consumption.

Figure 6: Traditional one-directional versus new bi-directional grid



Source: Own illustration adapted from Khalilpour and Vassallo (2015)

Van Vliet (2012, pp. 265–266) describes three roles for individuals in the energy system: *customer*, *citizen-consumer*, and *co-provider*. While the *customer* role focuses on the economic energy aspects, the *citizen-consumer* role rather relates to sustainability. Finally, individuals can be *co-providers,* generating electricity for self-consumption or others (see also Schot et al., 2016). In a smart grid, consumers need to balance between these different roles – incorporating economic considerations, but also environmental and privacy issues (van Vliet, 2012). The roles of individuals, e.g. as consumers, producers, investors or partners, are vital, now that new opportunities for engaging in the energy system have come into existence (see Stern, Sovacool, & Dietz, 2016; Wainstein & Bumpus, 2016).

Having considered the literature on the changing energy system, the context of Germany and the role of consumers, the following subsection provides an introduction to the three focus areas of the dissertation.

2.2. Focus areas of the dissertation

This section briefly provides some background to the dissertation's three focus areas along the value chain: a short overview of community-level energy solutions; an introduction to the role of battery storage systems; and information on electricity tariff adoption with a focus on spatial aspects.

2.2.1. Energy generation: Community energy *(ESSAY I)*

Communities and neighborhoods have been highlighted as promising avenues for energy technologies (e.g., Roselt et al., 2015). Community-based energy solutions, and in particular energy cooperatives, are an important pillar in the German energy transition (Bauwens, 2016; Yildiz et al., 2015). More than 810 cooperatives operate in the energy field in Germany, representing around 165.000 engaged citizens (DGRV, 2016). In 2013, community energy projects and individuals owned 47% of the total installed renewable energy capacity (trend:research/Leuphana Universität Lüneburg, 2013). The number of energy cooperatives rose steeply until 2011, while the number of newly founded organizations has been declining since this time (DGRV, 2016).

Community-based implementation represents a *new social practice* (Verbong et al., 2016, p. 33) and a social innovation (BMUB, 2016). Some of the potential benefits of community-based energy solutions are regional value creation, acceptance of renewable energy sites, engagement of citizens in sustainability issues, transparency, diversity of actors, and job creation. Moreover, community energy can help to make energy less abstract and more visible (Hauser et al., 2015). Although community energy plays an important role in the German energy transition, it is still a niche market. Insights on consumers' willingness to engage in community energy and on the role of social factors can help to gain a better understanding of consumer participation in the energy system and foster this engagement. Participation can drive changes in the energy system and influence the acceptance of these changes (Steg et al., 2015). However, too little is understood about the drivers of such participation – either by actively engaging in initiating and organizing such projects or by investing financial resources. This applies particularly when taking non-environmental factors into account. Hence, *Essay I* focuses on the social aspects of community-based energy solutions, examining the effect of trust, community identity, and social norms, as well as the impact of environmental motives on the willingness to voluntarily contribute to or financially invest in a local renewable energy project. The study explores the following research questions: *1. Are citizens willing to participate in community energy projects? 2. How do community identity, trust, and social norms influence the willingness to participate in community energy projects?* The essay analyzes the acceptance of and the support for local community-based energy generation from renewable sources including local storage and consumption.

2.2.2. Energy storage: Battery storage systems *(ESSAY II)*

A decentralized, renewable energy system faces challenges on the demand and supply side (Koirala et al., 2016; Verbong et al., 2013). The intermittency of renewable energies represents a key issue for a sustainable energy system, since it limits their value (Lewis, 2016).

Variable renewable energies can, for instance, deteriorate the stability of the grid (Verbong et al., 2013). This problem can be observed in countries with high shares of generation from wind and PV, e.g. in Denmark, Germany, Spain or the UK (IEA, 2016d). Strategies focusing on variable renewable energies need energy storage solutions to balance generation and demand (De Sisternes et al., 2016). Battery storage systems are one technology for addressing the intermittency nature of renewable sources, and although present battery systems are not cost-effective, there have been significant price decreases (Cucchiella, D'Adamo, & Gastaldi, 2016; Graditi, Ippolito, Telaretti, & Zizzo, 2016; Nykvist & Nilsson, 2015). The prices for battery storage systems decreased by 18% p.a. on the German market between 2013 and beginning of 2016 (Kairies et al., 2016). In that period, around 34.000 systems were installed in Germany – making it the main market for stationary battery storage systems globally (Kairies et al., 2016). The battery storage market is on the rise, but there is a lack of economic and socio-economic research on the end-user, i.e. their preferences and acceptance of storage technologies. Agnew and Dargusch (2015) state that the role of consumers and an understanding of their motivations is crucial for the further diffusion of battery storage systems and the configuration of the storage market. Storage systems are a particularly relevant technology because they cannot only offer private but also external value to the grid due to the various use cases (see M. Müller et al., 2017; Stephan, Battke, Beuse, Clausdeinken, & Schmidt, 2016). This is compounded by the fact that renewable energy technologies, and particularly battery storage systems, have been categorized as a disruptive innovation that could fundamentally change the energy system (Agnew & Dargusch, 2015; Galassi & Madlener, 2014; Islam, 2014; Lewis, 2016; Richter, 2013).

Few scholars have examined the motives and preferences for battery storage adoption and have mainly used standard survey methodologies (Gährs, Mehler, Bost, & Hirschl, 2015; Kairies et al., 2016; Römer, Reichhart, & Picot, 2014). No study has used a stated preference method to empirically investigate consumer preferences for different concepts of storage technologies and business models with joint usage, and not least focusing on Germany as the main market. Innovation and new business models are needed in order to support the diffusion of storage systems and overcome the barriers to their expansion, e.g. by reducing costs and increasing customer value. As ways of supporting the grid with different use cases, storage systems can contribute to balance the intermittency and allow for the further integration of variable renewable energies. Storage solutions at the community level are rather new to the market, but could offer various technical and financial benefits (Parra, Gillott, Norman, & Walker, 2015, 2016; Zeh, Rau, & Witzmann, 2016). Moreover, these new routes for implementing storage systems could generate value for the various parties involved, such as investors, consumers and grid operators. *Essay II* analyzes preferences for such battery storage systems focusing on implementation concepts and business models. The study addresses two research questions: *1. What are consumers' preferences for battery storage systems? 2. Which business models can foster the diffusion of battery storage systems and the further integration of renewable energies?* In this way, it explores business models and routes for residential and joint usage of larger storage systems, and consumer preferences for the provision of grid services. Moreover, autarky is investigated as a driver for PV and storage adoption and opportunities for new consumption modes are discussed.

2.2.3. Electricity tariffs (*ESSAY III*)

Generating electricity from renewable sources is key for sustainable development, and storage solutions are needed to balance supply and demand. However, consumers also need to adopt renewable energy tariffs to support sustainable energy supply and the expansion of renewable energies. Depending on their network area, German consumers can, on average, choose between 91 electricity suppliers offering different tariffs (Bundesnetzagentur/ Bundeskartellamt, 2015). The power providers can be categorized into the following types: (1) the *big four*: the biggest providers on the German market (E.ON, RWE, EnBW and Vattenfall) (bdew, 2013b), (2) regional and local power providers (from large-sized regional utility companies such as MVV Energie or Stadtwerke München, to small local utilities), (3) specialized providers for green electricity (e.g., LichtBlick, Polarstern), (4) cooperatives and other community energy companies (e.g., Bürgerwerke). Reichmutz (2014) presents a detailed analysis of the market for so-called green electricity in Germany. Currently, around 17% of the German households purchase a renewable tariff, that is, electricity generated exclusively from renewable sources (Bundesnetzagentur/Bundeskartellamt, 2014).

Studies on consumer preferences for electricity tariffs have found a willingness to pay for green electricity (Herbes, Friege, Baldo, & Mueller, 2015; Kaenzig, Heinzle, & Wüstenhagen, 2013) and different customer segments of renewable energy adopters (Tabi, Hille, & Wüstenhagen, 2014). According to Rommel et al. (2016), consumers are willing to pay a premium for green energy purchased from cooperatives and public utilities. Since the German energy transition is a decentralized phenomenon, an increasing number of generation sites are located in proximity to the consumers. Hence, there might be opportunities to market electricity locally or regionally. In addition, a bill has recently passed in Germany allowing producers to market such regionally generated electricity from renewable sources (EEG, 2016). Moreover, the marketing of regionally generated electricity is being promoted by regional energy concepts and an increasing number of regions or municipalities aiming for energy self-sufficiency (see Engelken, Römer, Drescher, & Welpe, 2016).

In a decentralized energy system with generation and storage on the local and regional levels, tariffs offering regionally generated electricity could find their way into the mainstream market. Nevertheless, consumers' attitudes towards and preferences for local or regionally generated electricity are still unclear. Many commentators mentioned a *not-in-my-backyard* (NIMBY) effect – broadly defined as a positive attitude towards renewable energy sites in general, but a resistance against the deployment of renewable energy facilities in their immediate surroundings (Friedl & Reichl, 2016; Lienert, Suetterlin, & Siegrist, 2015). However, this concept and its use have been criticized by researchers like Batel and Devine-Wright (2015) and Swofford and Slattery (2010). The concept would be oversimplifying and, hence, not adequate to explain real-world attitudes (Wolsink, 2012b). A recent study indicates potential preferences for local and regional deployment of energy supply (Ebers & Wüstenhagen, 2016). To this end, *Essay III* explores preferences for locally and regionally generated electricity. The study addresses the following research questions: *1. What are consumers' attitudes towards and preferences for electricity from renewable sources generated close to the end-user? 2. What are consumer preferences regarding electricity tariffs focusing on regional generation and the regional ties of the power provider?* In this way, it focuses on proximity of generation and provider, investigating electricity tariffs characterized by different levels of electricity mixes, local generation, providers and monthly costs.

With the consideration of these specific focus areas in mind, the following section presents the research approach.

2.3. Research approach

2.3.1. Methodological background

This dissertation aims to analyze and understand consumers' choices, behaviors and intentions to act in the field of energy. The essays center on attitudes and preferences with regard to participation in community energy projects, purchase of battery storage systems and choice of electricity tariffs. To answer the research question in *Section 1.3.1*, the data was collected using two different methods, namely, attitude and preference measures.

Attitudes and preferences are key concepts in consumer research and psychology (Cacioppo, Gardner, & Berntson, 1997; Nowlis, Kahn, & Dhar, 2002; Simonson, Carmon, Dhar, Drolet, & Nowlis, 2001). While attitudes are more a psychological concept, preferences are a concept in economics (Kahneman, Ritov, & Schkade, 1999). Attitudes can be defined as *a psychological tendency that is expressed by evaluating a particular entity with some degree of favor or disfavor* (Eagly & Chaiken, 1998, p. 269). Preferences are *attitudes toward one object in relation to another* (Blackwell, Miniard, & Engel, 2001, p. 289). According to Kahneman et al. (1999, p. 205) they are a narrower, more specific concept than attitudes: *In contrast to economic preferences, which are about commodity bundles (Varian, 1984), objects of attitudes include anything that people can like or dislike, wish to protect or to harm, want to acquire or to reject.* While attitudes are multidimensional (Ajzen, 2005), preferences can be seen as one-dimensional indicators and are usually measured within a choice paradigm.

2.3.2. Overview of data collection and analysis

Two online surveys with different samples were conducted in Germany to collect the data for this dissertation. The data for *Essay I* and *III* was collected from July to August 2014 in collaboration with the market research company *GfK* (*Survey 1*). The final sample for the analysis consisted of 954 respondents, of which 780 are household decision-makers (persons in charge of energy-related and financial decisions in their respective households), and 174 are owners of a renewable energy system. The sample of the household decision-makers was drawn by quota sampling. It is representative of the German population with respect to age, education, employment status and income.

Data collection for *Essay II* was carried out from March to April 2016 in cooperation with the market research institute *skopos* and support from two German solar energy associations (*Deutsche Gesellschaft für Sonnenenergie e. V.*; *Solarenergie-Förderverein Deutschland e. V.*) (*Survey 2*). Respondents from the latter group were recruited through the email newsletter of the respective association. In addition, a link to the survey was posted on an active German PV internet forum (*www.photovoltaikforum.com*). We offered the respondents recruited via the associations and the internet forum to enter in a lottery for either a shopping voucher or a charitable donation (75 €, 50 € and 25 € four times each), to increase the response rate and encourage them to complete the online-questionnaires in full. The final sample for the analysis of *Survey 2* consisted of 836 respondents, with 752 adopters of a PV system and 84 interested non-adopters.

Both surveys contained two parts: (1) a standard questionnaire format and (2) a discrete choice experiment; *Essay I* analyzes attitude-based data from the standard questionnaire part of *Survey 1*, using multiple regression analyses and mediation analyses. *Essay III* uses the choice data from the same survey which is analyzed via discrete choice modelling, more specifically, based on the random parameters logit model. The choice data from *Survey 2* was analyzed in *Essay II*, also by applying a random parameters logit model. In addition, *Essay II* and *Essay III* include some Likert-type measures from the standard questionnaire part.

2.3.3. Measurement of attitudes and preferences

Consumer attitudes, choices and preferences can be measured in various ways (Louviere, Hensher, & Swait, 2000; Phillips, Johnson, & Maddala, 2002). *Essay I* focusses on attitude-based measures and

Essays II and *III* apply a preference approach (discrete choice). Both types of measures are briefly introduced.

2.3.3.1. Attitudes

Cacioppo et al. (1997) highlight the impact of attitudes on decision-making and consumer behavior (see also Blackwell et al., 2001). Attitudes are an essential component of the Theory of Reasoned Action and the Theory of Planned Behavior (Ajzen, 2014; Madden, Ellen, & Ajzen, 1992). Following the Theory of Planned Behavior, attitudes – besides subjective norm and perceived behavioral control – influence the intention to perform a specific behavior, which in turn has an effect on actual behavior (Ajzen, 1991). Hence, attitudes have an indirect effect on behavior through behavioral intentions.

In *Essay I* an attitude-based measure of willingness to participate in a community energy project was applied, focusing on social determinants of human behavior. There is a considerable body of literature on attitudes in the energy field (e.g., Claudy, Peterson, & O'Driscoll, 2013; Gadenne, Sharma, Kerr, & Smith, 2011; Owens & Driffill, 2008). The essay on community energy specifically centers on the impact of community identity, social norms and trust – factors that only a few studies have analyzed before. More specifically, the impact of these factors on community energy is new and offers a novel perspective on the literature. In the remainder of this subsection, these three constructs are introduced.[9]

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[9] Besides the main constructs of the study, the New Ecological Paradigm scale was included to measure and analyze the effects of environmental concern (Dunlap et al., 2000).

First, community identity can, in a nutshell, be described as a feeling of attachment to a respective community (van Vugt, 2002). The measure used in *Essay I* is based on Tyler & Degoey (1995), studying community effects in the context of a water shortage, and van Vugt (2001), focusing on the effect of community identification in a similar context. In the energy field, for instance, Bomberg and McEwen (2012), DeVincenzo and Scammon (2015), and Koirala et al. (2016) analyze community identity or a sense of community.

Second, social norms, also called subjective norms, are a *person's perception of social pressure to perform or not perform the behavior under consideration* (Ajzen, 2005, p. 118). They are an important component of the Theory of Planned Behavior. Social norms have been the subject of investigation in some energy studies (e.g., Bauwens, 2016; Hatzl, Brudermann, Reinsberger, & Posch, 2014; Steg et al., 2015). The norm measure used in this dissertation is adapted from Hatzl et al. (2014) and focuses on social norms surrounding the energy aspects of this study (renewable energy, energy saving and community energy).

Third, trust can affect cooperation and citizen participation (Tyler & Degoey, 1995). The role of trust in energy studies has been stressed by Greenberg (2014) and Walker et al. (2010). Wüstenhagen et al. (2007), Bauwens (2016), and Goedkoop and Devine-Wright (2016) have all published studies in the energy field referring to the role of trust. This study used the well-established measure of general trust developed by the European Social Survey (2012).

2.3.3.2. Preferences

Besides the attitudinal measures applied in *Essay I*, preference measures are used in *Essays II* and *III*. Preferences are *attitudes toward one object in relation to another* (Blackwell et al., 2001, p. 289) that can be measured using stated preference methods such as discrete choice analysis. Choice experiments are based on microeconomic theory. The roots of this approach can be traced back to random utility theory (McFadden, 1974; Thurstone, 1927), and the new approach to consumer theory (Lancaster, 1966).[10] While the method was originally based on utility maximization, today it also incorporates choice architectures and preferences heterogeneity (e.g., Louviere et al., 2008).

Choice experiments can be characterized as scenarios (choice sets) in which a decision-maker chooses among different alternatives, e.g. configurations of a product (Train, 2009). Respondents are typically shown a set of different product configurations and are asked to choose the alternative (or none-option) that they prefer (Buryk, Mead, Mourato, & Torriti, 2015; Hensher & Greene, 2003). An advantage of choice experiments is that participants need to trade-off between different alternatives and characteristics of the object under investigation (Auger & Devinney, 2007).[11]

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[10] Random utility theory states that decision-makers choose the alternative from a set of options that maximizes their utility (Train, 2009). Lancaster's (1966, p. 154) theory proposes *that goods possess, or give rise to, multiple characteristics in fixed proportions and that it is these characteristics, not goods themselves, on which the consumer's preferences are exercised.* Hence, the utility of an alternative is composed of its different attributes.

[11] The elicitation of preferences using discrete choice experiments – trading off attributes in the choice sets – can increase the reliability of the outcome (Auger & Devinney, 2007). Choice experiments have further benefits such as eliminating the political correctness bias (Auger, Burke, Devinney, & Louviere, 2003).

The choice experiment method is applied in many disciplines, such as transportation research (e.g., Hensher & Greene, 2003), agricultural economics (e.g., Lusk, Roosen, & Fox, 2003), and environmental economics (e.g., Hanley, Wright, & Adamowicz, 1998). Furthermore, discrete choice methods are used in the energy field to measure preferences and willingness to pay for various energy products, such as energy services (Hensher, Shore, & Train, 2014), energy retrofitting (Achtnicht & Madlener, 2014), or wind farm deployment (Ek & Persson, 2014). Moreover, choice experiments or conjoint analyses have been used to analyze electricity tariff choice in particular (e.g., Burkhalter, Kaenzig, & Wüstenhagen, 2009; Buryk et al., 2015; Tabi et al., 2014). In this dissertation, the discrete choice method is applied in *Essay II* to investigate consumer preferences for and business model configurations of battery storage systems, and in *Essay III* to examine preferences for electricity tariffs.

Having presented the methodological background of the empirical studies, Table 1 provides an overview of the three focus areas of this dissertation, including the research questions and the key findings.

Table 1: Overview of the specific research questions and key findings

	Research topic	Research questions	Key findings
ESSAY I	Community energy	1. Are citizens willing to participate in community energy projects? 2. How do community identity, trust, and social norms influence the willingness to participate in community energy projects?	▸ The attitude towards energy generation at the local and regional levels is positive, as is the attitude towards community energy projects. ▸ The willingness to participate in community energy projects with the objective of local generation, storage and usage is relatively high. ▸ Willingness to volunteer is higher than willingness to invest. ▸ Social aspects, i.e. social norms and trust, play an important role for community energy besides environmental motivations. ▸ Trust and social norms mediate the relationship between community identity and willingness to participate. ▸ Owners of a renewable energy system and people in suburban or rural areas are more willing to participate.
ESSAY II	Battery energy storage	1. What are consumers' preferences for battery storage systems? 2. Which business models can foster the diffusion of battery storage systems and the further integration of renewable energies?	▸ There is high interest in purchasing a battery storage system among potential adopters, provided the price be reasonable. ▸ There is market potential for residential and community storage systems. ▸ Price, autarky and ownership are key product attributes of battery storage systems. ▸ Consumers value high levels of autarky. ▸ Consumers want to control their storage systems, but are willing to relinquish some control to provide grid support. ▸ Regional power providers and local cooperatives are the preferred partners for maintenance and control of storage systems.
ESSAY III	Energy tariffs	1. What are consumers' attitudes towards and preferences for electricity from renewable sources generated close to the end-user? 2. What are consumer preferences regarding electricity tariffs focusing on regional generation and the regional ties of the power provider?	▸ Price is the most important product attribute of tariffs, followed by the electricity mix. ▸ Consumers prefer energy tariffs offering a renewable energy mix. ▸ Consumers show a preference for a share of regional generation in their electricity mix, but willingness to pay flattens out with higher shares. ▸ The preferred power providers are regional energy companies and local cooperatives.

Source: Own illustration

3. Three essays

3.1. Citizens’ willingness to participate in local renewable energy projects: The role of community and trust in Germany *(ESSAY I)*[12]

Abstract

Citizen participation can be an important means for energy transitions at the local level. However, little is known about citizens’ willingness to engage in community-based renewable energy projects, and its determinants. This paper analyzes how community identity, social norms, trust and environmental concern foster or constrain citizens’ willingness to take part in community energy schemes. We survey individuals who are in charge of energy-related and financial decisions in their households, and owners of renewable energy systems. We find that the general attitude toward community energy is positive. Willingness to volunteer is higher than willingness to invest money. Regression analyses show that social norms, trust, environmental concern and community identity are important determinants of willingness to participate in community energy. However, using mediation analyses we find that the effect of community identity occurs

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[12] *Essay I* is based on Kalkbrenner, B. J., Roosen, J., 2016. Citizens’ willingness to participate in local renewable energy projects: The role of community and trust in Germany. *Energy Research & Social Science*, 13, 60–70. doi:10.1016/j.erss.2015.12.006.

Bernhard Kalkbrenner designed the study, performed the analyses and wrote the paper. Jutta Roosen provided advice on the data analysis and the development of the paper as well as editorial input.

through changes in social norms and trust. Both ownership of a renewable energy system and living in a rural, rather than urban community, increase the likelihood of participation. This study helps to understand the principles underpinning the willingness to participate in community energy and underlines its potential. Our insights emphasize the importance of social, rather than merely environmentally motivated aspects, and extend literature on pro-environmental behavior.

Keywords: Citizen participation, Community energy, Community identity, Energy transition, Pro-environmental behavior, Social norms

3.1.1. Introduction

In order to successfully manage energy transitions, the acceptance and support of citizens is essential. Community energy projects are *an emergent phenomenon* (van der Schoor & Scholtens, 2015, p. 674) and provide the opportunity for citizens to actively engage in the community and the local energy system. Rather than participating as mere energy consumers, members of the public are currently able to assume a number of different roles within the energy system, as they are able to influence the ways and the extent to which energy is produced (Stern, 2014). Along with these new roles new possibilities to engage and participate have developed (Bomberg & McEwen, 2012; Devine-Wright, 2007). The importance of civil society groups for transformations towards an environmentally friendly energy system in countries such as the UK, Germany and the USA has been highlighted (Aylett, 2013; Blanchet, 2015; Viardot, 2013).

Community energy projects are *organisations, initiated and managed by actors from civil society, that aim to educate or facilitate people on efficient energy use, enable the collective procurement of renewable energy or technologies or actually provide (i.e. generate, treat or distribute), energy derived from renewable resources for consumption by inhabitants, participants or members* (Boon & Dieperink, 2014, p. 298). Energy cooperatives are a prominent example of community energy in Germany. They are an essential force within the German energy transition, with a growing number of members and investments (Yildiz et al., 2015). Germany is a forerunner towards an energy system based on renewables (Yildiz et al., 2015), has opted for a *regime shift* (Strunz, 2014, p. 154), and decided to increase the share of electricity generated from renewables to 55-60% of gross electricity consumption by 2035 and phase out all nuclear power plants by 2022 (BMWi, 2014b; EEG, 2014). The German case is of particular interest for analyzing transitions at the local and regional level due to the fact that this national transition is a *highly decentralised phenomenon* (J. Mattes et al., 2015, p. 258) with support of individuals and larger local initiatives (Fuchs & Hinderer, 2014; Kungl, 2015; J. Mattes et al., 2015; Römer et al., 2012).

Various aspects of community energy have been studied in the last few years (Hoffman & High-Pippert, 2010; J. Mattes et al., 2015; Walker & Devine-Wright, 2008; Walker, Hunter, & Devine-Wright, 2007). Most papers on community energy have employed a qualitative approach in their examination, analyzed the concept theoretically (Hoffman & High-Pippert, 2010; J. Mattes et al., 2015; Rogers, Simmons, Convery, & Weatherall, 2012; Walker & Devine-Wright, 2008; Walker et al., 2007) or focused on the legal framework (Romero-Rubio & de Andrés Díaz, 2015). Recently, Bamberg et al. (2015) tested willingness to participate in community-based pro-environmental projects using different theoretical models. However, quantitative research on the participation of citizens is lacking, and little is known about citizens' attitudes towards local energy and their willingness to engage in community-based renewable energy projects. It is unclear which factors influence citizens' willingness to volunteer for a community energy project or invest financial resources and the need for such research has been highlighted by Aylett (2013) and Wandersman et al. (1987). In response to this need, the current study investigates citizens' willingness to participate in community energy projects, in terms of volunteering and investment of financial resources. These two types of participation have been mentioned (Fraune, 2015), but their joint analysis has been neglected in earlier studies.

In this article, we focus on community identity and trust as determinants for willingness to participate in community energy projects. We consider contributing to a community energy project a pro-environmental behavior (Stern, 2000). Research on the tendency towards collective action – in particular pro-environmental behavior (Brewer & Stern, 2005) – can help to better understand citizens' willingness to actively engage in community energy and the underlying dynamics towards more sustainable consumption. To develop effective strategies to encourage active participation and financial investment in community energy it is important to understand which factors influence the willingness to participate. This understanding can be utilized to induce a desired behavior (Turaga, Howarth, & Borsuk, 2010), e.g. in order to reduce emissions (Dasgupta, Southerton, Ulph, & Ulph, 2016).

A sense of community and trust are needed, in order to achieve a high acceptance and willingness to participate in community energy projects (Walker et al., 2010). The importance of trust, community, and social norms has been stressed by various studies (Greenberg, 2014; Seyfang & Smith, 2007; Thøgersen & Grønhøj, 2010; Walker et al., 2010; Wüstenhagen et al., 2007), e.g., Greenberg (2014) highlights the impact of trust and its *underappreciation* in the energy sector. However, the influence of the mentioned factors on citizen participation in energy projects remains unknown. Therefore, we suggest that community identity, trust, social norms and environmental concern are fundamental determinants of the willingness to participate. We thereby address the following questions:

1. Are citizens willing to participate in community energy projects?
2. How does community identity influence the willingness to participate in community energy projects?
3. How does trust influence the willingness to participate in community energy projects?
4. How do social norms influence the willingness to participate in community energy projects?

We answer these research questions by analyzing data from Germany. In order to examine the determinants of the willingness to participate in community energy projects multiple regression analyses and mediation analyses are applied.

3.1.2. Literature review and hypotheses

3.1.2.1. Community energy, participation and pro-environmental behavior

Community energy

Community energy involves energy production, collective procurement, distribution or conservation initiatives (Boon & Dieperink, 2014; Sadownik & Jaccard, 2001; Seyfang, Park, & Smith, 2013). In addition, solutions such as energy storage could be part of community energy initiatives. Community energy projects are defined by, but also differ in, governance structure and participation, ownership, technology and local consumption (Hoffman & High-Pippert, 2010). Various forms of community energy currently exist, such as groups of local individuals investing in renewable energies, citizen wind parks or cooperatives in the field of electricity or heating (Bauwens, Gotchev, & Holstenkamp, 2016; Hoffman & High-Pippert, 2010; Romero-Rubio & de Andrés Díaz, 2015). Community projects within the energy sector are characterized by the involvement of stakeholders from the local communities, assuming roles such as investors or contributors (Hoffman & High-Pippert, 2010; Huijben & Verbong, 2013). Boon and Dieperink (2014) found that involvement, participation and the possibility of co-ownership are important factors for the support of community energy. Depending on the particular type of project, a range of positive outcomes can be expected such as energy savings or a climate-friendly energy system. Moreover, community energy projects are able to foster the psychological engagement with renewable energies (Rogers et al., 2012), promote *energy responsibility* (Frantzeskaki, Avelino, & Loorbach, 2013, p. 102), raise awareness or support the local economy (Romero-Rubio & de Andrés Díaz, 2015; UK Department of Energy & Climate, 2013), foster energy transitions towards renewables (Hoffman & High-Pippert, 2010), avoid opposition and implementation problems (Walker et al., 2010) and provide a playground for social innovations (Mulugetta, Jackson, & van der Horst, 2010). Frantzeskaki et al. (2013) and Mattes et al. (2015) emphasize the relevance of individuals and cooperatives for energy transitions at the local level (see also Yildiz et al., 2015). Motivations for collective energy action have economic, environmental and social grounds, and are also concerned with energy policy considerations, such as the decentralization of the energy system and energy self-sufficiency (Accenture, 2013; Bomberg & McEwen, 2012; Klemisch, 2014; UK Department of Energy & Climate, 2013; van der Schoor & Scholtens, 2015). Among the factors that positively influence the initiation of local renewable energy organizations are environmental awareness and energy autarky intentions (Boon & Dieperink, 2014).

Community energy and citizen participation are fundamental components of the German energy transition (Fraune, 2015). More than 970 energy cooperatives are registered in Germany (J. R. Müller & Holstenkamp, 2015; Yildiz et al., 2015), most of them focusing on energy production from renewable sources and investment in renewables (Debor, 2014). Solar energy, onshore wind as well as bioenergy are commonly viewed as dominant within the field of community energy in Germany (Yildiz, 2014). Fraune (2015, p. 57) describes the German case of community energy as *a reference point in revealing the impact of the larger social, cultural and political context on citizens' capabilities to participate and thus to benefit from citizen* *participation schemes.* Several recent studies provide in-depth information on community energy in Germany (Fraune, 2015; Romero-Rubio & de Andrés Díaz, 2015; Yildiz et al., 2015).

Participation and pro-environmental behavior

Community projects rely on their members' involvement and participation, e.g. as volunteers and investors (Seyfang & Smith, 2007; Verba, Schlozman, & Brady, 1995; S. Wirth, 2014). Citizen participation has been defined as *a process in which individuals take part in decision making in the institutions, programs and environments that affect them* (Heller, Price, Reinharz, Riger, & Wandersman, 1984, p. 339). Different kinds of initiatives and different degrees of participation exist (Hoffman & High-Pippert, 2010; Walker & Devine-Wright, 2008). Community projects, just like social movements, need not only active members, but also other supporters (Fraune, 2015; Stern & Dietz, 1999). The impact of citizen participation in communities is discussed in various studies (Boyte, 2003; Florin & Wandersman, 1990; Foster-Fishman, Collins, & Pierce, 2013). Recently, Sovacool and Brown (2015) as well as Shaw et al. (2015) highlighted participation in energy issues.

Community energy projects represent collective action towards renewables. The relevance and efficacy of collective action and citizen activism to tackle climate change has been highlighted (Alisat & Riemer, 2015; Ockwell & Whitmarsh, 2009; Roser-Renouf, Maibach, Leiserowitz, & Zhao, 2014). However, research on and knowledge of the effective involvement and collective pro-environmental action is lacking (Alisat & Riemer, 2015). In general, involvement depends on the risks and costs, and the outcome for the individual and the society

(Broman Toft, Schuitema, & Thøgersen, 2014; Verplanken, 2002). Willingness to participate in local energy projects is generally low, since positive outcomes, such as environmental benefits, are distributed among participants as well as non-participants – representing a free-riding behavior (Bomberg & McEwen, 2012). Local engagement, sustained participation and financial resources as well as expertise and governmental support are needed for the mobilization and success of community energy (Bomberg & McEwen, 2012; Mulugetta et al., 2010). Participation in community energy is promoted by contacts at the local neighborhood level (Hoffman & High-Pippert, 2010). Hoffman and High-Pippert (2010) argue that sustained participation is motivated by community benefits rather than personal benefits.

We take these findings into account and analyze the general attitude towards community energy, and the active participation by volunteering (e.g. organizing and managing the projects) and financial investment as two types of participation (Fraune, 2015). First, we define volunteering as providing voluntary work without compensation for the community or non-profit organizations (Cnaan, Handy, & Wadsworth, 1996; Snyder & Omoto, 2008). The relevance of volunteering in contemporary society, e.g., to address societal problems, and the possibilities to engage in voluntary service are growing (Bekkers, 2012; Brudney & Meijs, 2013; Snyder & Omoto, 2008). Recently, various studies have been analyzing volunteerism from different perspectives and different motivations for volunteering have been shown to exist (García-Valiñas, Macintyre, & Torgler, 2012; John Wilson, 2012). Moreover, determinants such as higher income and education, and home-ownership tend to increase the willingness to volunteer (Dury et al., 2015; Rotolo, Wilson, & Hughes, 2010). Participation in the community and volunteering can facilitate a *sense of community* (Bekkers, 2012, p. 225).

Besides initiators and active supporters of community energy organizations, financial resources are essential to realize the projects. Both financial and non-financial incentives to invest in community energy exist (Bomberg & McEwen, 2012). Financial investments provide the essential funding to develop community energy projects and community energy offers the opportunity for collective green investment. Financial issues are a key barrier for community projects, in particular the initial financing of the projects (Bomberg & McEwen, 2012).

3.1.2.2. Factors influencing participation in community energy

Various approaches have been used to study pro-environmental behavior (see Vining & Ebreo, 2002). A wide range of studies use established theories to analyze pro-environmental behavior and consumer behavior, e.g., Norm Activation, Value Belief-Norm Theory, or Theory of Planned Behavior (Gifford & Nilsson, 2014). We focus on a set of factors that analyze willingness to participate in community energy projects in terms of trust and community aspects. Community energy projects are pro-environmental actions and build on the respective community and the people initiating and contributing towards the projects. Hence, the identification with the community and the environmental attitude seem to be essential factors. Moreover, the influences of trust towards people and social norms are proposed to be determining factors of community energy participation. This line of reasoning is supported by the findings of Gadenne et al. (2011).

Community identity

The willingness to contribute to the community depends on citizens' social connections to their community or a specific institution (Hoffman & High-Pippert, 2010; van Vugt & Cremer, 1999; Verba et al., 1995). Having a strong identification and connection strengthens citizen collaboration and action (Bomberg & McEwen, 2012; Tyler & Degoey, 1995). Community identity can mobilize action (Bomberg & McEwen, 2012) and shift the interests of individuals from being self-oriented to being community-oriented (van Vugt, 2001). Community identity can be summarized as: *Feelings of attachment to the community, taking pride in the community, and having friends within the community* (van Vugt, 2002, p. 797). Community organizing and participation not only builds a sense of community (Chavis & Wandersman, 1990; McMillan & Chavis, 1986), but also leads to benefits such as higher tolerance and trust or well-being at the individual level (see Christens & Speer, 2011). Community energy projects can facilitate solidarity with the community, but solidarity can also be the outcome of projects (Bomberg & McEwen, 2012; van der Horst, 2008). The shared intention to make the community a *better place* can be an important element for the success of local renewable energy projects (Hoffman & High-Pippert, 2010), e.g., Hagget and Aitken (2015) underline the importance of community identity, which seems to foster community-based action. Drawing upon these findings, we hypothesize the following:

Hypothesis 1.1. People with higher community identity have a higher willingness to participate in a local community energy project.

Trust

Recently, a growing body of literature is being directed towards the concept of trust (Crepaz, Polk, Bakker, & Singh, 2014; Hobbs & Goddard, 2015) – including that of energy research (Greenberg, 2014; Raven, Mourik, Feenstra, & Heiskanen, 2009; Sovacool, 2014). Sabel (1993, p. 1133) defines trust as *the mutual confidence that no party to an exchange will exploit the other's vulnerability.* A definition by Rousseau et al. describes trust as *a psychological state comprising the intention to accept vulnerability based upon positive expectations of the intentions or behaviour of another* (Rousseau, Sitkin, Burt, & Camerer, 1998, p. 395). Trust is a fundamental concept of interpersonal relationships and collaboration (Declerck, Boone, & Emonds, 2013; Misztal, 1996). A higher degree of trust in others has been shown to increase citizen participation or engagement (see Tyler & Degoey, 1995).

Although Putnam (2000) found that trust and civil engagement are characterized by a positive correlation, Delhey and Newton (2003) claim that this relationship is more complex. Trust is positively related to volunteering and trust in people is relevant for *action that bridges group boundaries* (Welzel, 2010, p. 155). Moreover, trust has been shown to be crucial for economic decision-making, such as financial investments (Ding, Au, & Chiang, 2015). Walker et al. find that trust is essential for the development of community energy, and argue that *trust is both a necessary characteristic and a potential outcome of cooperative behaviour* (Walker et al., 2010, p. 2657). Wiersma and Devine-Wright

(2014) stress the importance of trust for decentralized energy projects. However, existing research has largely neglected the analysis of trust within the context of community energy. Notable exceptions are Walker et al. (2010) and Yildiz et al. (2015). The review leads us to the following hypothesis regarding general trust:

Hypothesis 2. Trust positively influences willingness to participate in a local community energy project.

Besides the direct effect of trust on the willingness to participate, we propose an interaction of community identity with general trust. Flanagan argues *that in relationships with peers and especially friends we learn what it means to trust and to be trusted* (Flanagan, 2003, p. 165). Hence, community and the identity with the community seem to influence trust. We expect that community identity has an association with trust, namely that higher community identity is associated with higher levels of trust. Consequently, we hypothesize that community identity has an effect on citizens' willingness to participate through changes in trust, and propose the following hypothesis:

Hypothesis 1.2. Trust mediates the effect of community identity on the willingness to participate in a local community energy project.

Social norms

Overall, cooperation is among others influenced by social norms (García-Valiñas et al., 2012). Social norms are a *person's perception of social pressure to perform or not perform the behavior under consideration* (Ajzen, 2005, p. 118). Social norms can be driving forces of behavior

(Ajzen, 1991; Bamberg, 2003; Owens & Driffill, 2008). We include social norms in a way, which is in line with subjective norms of Ajzen and Fishbein (2005). They state that *(w)hen people believe that most respected others would expect them to perform the behavior or are themselves performing the behavior, the subjective norm will exert pressure to engage in the behavior* (Ajzen & Fishbein, 2005, p. 193).

Biel and Thøgersen (2007) found a positive effect of social norms on cooperative behavior when people are faced with social dilemmas. The influence of social norms on social and environmentally-related behavioral habits of consumers has been previously analyzed (Dwyer, Maki, & Rothman, 2015; Gadenne et al., 2011; McDonald & Crandall, 2015; Thøgersen & Grønhøj, 2010) and the impact of social norms on community energy has been highlighted (2010). Rathi and Chunekar (2015) underline the importance of social norms and their influence on decision-making in the field of energy research, as do Gifford and Nilsson (2014) in their review on pro-environmental behavior. In accordance with such findings, we propose the following hypothesis:

Hypothesis 3. A higher level of energy-related social norms positively influences willingness to participate in a local community energy project.

Besides the direct effect of social norms on participation, we propose an interaction of community identity with social norms. Social norms are *obstacles whose function is to deemphasize egoistic incentives – on behalf of a choice that is better for the collective* (Biel, Borgstede, & Dahlstrand, 1999, p. 246). Identification with the local community *is* *assumed to induce changes in people's attitudes and behaviors, bringing them closer in line with the needs of the community* (van Vugt, 2001, p. 1442), and common social norms are a central characteristic of communities (Varman & Costa, 2008). Hence, conforming to the expectations of the community is similar to how people comply with social norms. Therefore, we hypothesize that a strong connection with the local community has a relationship with the influence of the expectations of the respective neighbors or acquaintances. We expect community identity to have an effect on citizens' willingness to participate through changes in social norms. Consequently, we propose the following hypothesis:

Hypothesis 1.3. Energy-related social norms mediate the effect of community identity on the willingness to participate in a local community energy project.

Environmental concern

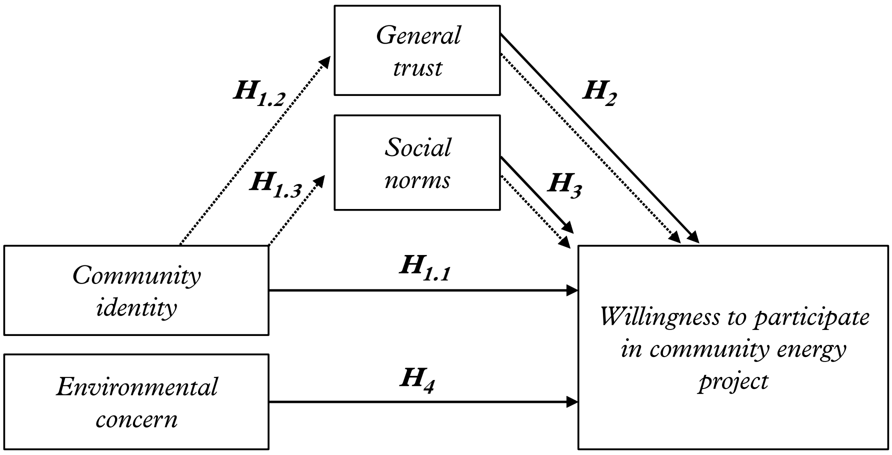
Determinants of environmental attitudes or concern and their influence on decision-making have been analyzed in many previous studies (e.g., Chen, 2014; Fraj & Martinez, 2006; Gadenne et al., 2011; Pienaar, Lew, & Wallmo, 2013). High environmental concern is shown to have a positive effect on pro-environmental behavior (Kilbourne & Pickett, 2008). Environmental reasons have been found to be among the motivations for collective energy action (Accenture, 2013; Bomberg & McEwen, 2012; Klemisch, 2014; UK Department of Energy & Climate, 2013; van der Schoor & Scholtens, 2015), as demonstrated by Boon and Dieperink (2014), whose study revealed a positive effect of environmental awareness on support for local energy projects. Hence, we propose the following hypothesis:

Hypothesis 4. Environmental concern positively influences willingness to participate in a local community energy project.

3.1.2.3. Conceptual model

Drawing on the aforementioned hypotheses, we propose and test a conceptual model that examines factors affecting willingness to participate in community energy projects focusing on the analysis of specific determinants derived from literature. Hence, our conceptual model contains four main components: Community identity, trust, social norms and environmental concern. Furthermore, we include socio-demographic factors in our analysis, since differences regarding the participation in community energy are shown to exist (Fraune, 2015). Figure 7 presents our proposed integrative model graphically. Continuous arrows illustrate variables included in step 1 of our analysis. In step 2 we focus on the analysis of the dotted arrows.

Figure 7: Conceptual model of the community energy study



Source: Own illustration

3.1.3. Data and methods

3.1.3.1. Data

Data were collected in July-August 2014 by means of an online survey in Germany. The survey was carried out by a professional market research institute *(GfK)*. Sampling proceeded in two steps: first, individuals who are in charge of energy-related and financial decisions concerning their private households were recruited. This group was drawn by quota sampling representative of age (+18 years), education, employment status and monthly net household income. Second, we targeted persons who have a renewable energy system, for example a solar energy system, in place. A total of 1021 persons completed the online survey. After plausibility checks, the final sample consisted of 954 respondents – 780 individuals that are in charge of energy-related and financial decisions in their households and 174 owners of renewable energy systems. Table 2 gives an overview of the sample characteristics.

Table 2: Sample characteristics (Online survey 2014)

Variables	Sample (N = 954) Frequency Absolut	Sample (N = 954) Frequency (%)	German average [a] Frequency (%)
Gender			
Female	435	45.6	51.2
Male	519	54.4	48.8
Age			
18 - 24 years	85	8.9	9.8
25 - 29 years	65	6.8	7.3
30 - 39 years	143	15.0	14.3
40 - 49 years	195	20.4	20.1
50 - 64 years	295	30.9	24.6
65 years and older	171	17.9	24.0
Highest professional qualification			
No professional qualification	158	16.6	24.1
Apprenticeship, vocational training in the dual system	452	47.4	47.7
Certificate from a specialized technical colleges	106	11.1	11.0
Qualification from a specialized academy or a college of advanced vocational studies	25	2.6	1.6
Qualification from a university of applied sciences	82	8.6	6.0
University degree	111	11.6	8.2
Doctorate	20	2.1	1.4
Employment status			
Employed	576	60.4	59.2
Unemployed	47	4.9	5.7
Pensioner	242	25.4	25.1
Pupil / Student	28	2.9	2.5
Other	61	6.4	7.4
Average monthly net household income (in EURO)			
less than 900	55	6.9	8.7
900 – 1.299	67	8.4	11.5
1.300 – 1.499	51	6.4	5.8
1.500 – 1.999	126	15.8	14.7
2.000 – 2.599	131	16.4	14.4
2.600 – 3.599	178	22.3	17.3
3.600 – 4.999	126	15.8	14.6
at least 5.000	66	8.2	13.1
do not know / not applicable	154		
Type of community			
Urban	435	45.6	-
Suburban or rural	519	54.4	-
Ownership of renewable energy system			
No renewable energy system in place	780	81.8	-
Owner of renewable energy system	174	18.2	-

[a] Percentages of the German average were provided by the market research company *GfK* based on the census and the income and expenditure survey (Federal Statistical Office).

Source: Own illustration

3.1.3.2. Measures

The online survey contained questions about trust, community identity, environmental concern and behavior, the energy system and community energy, as well as social norms, in that order. These questions were mixed with questions not used for the present article. We primarily employed existing scales to measure the constructs of concern. The main constructs were measured as follows.

Attitudes towards local renewables and community energy. We included a measure on public attitude towards local energy generation based on renewables (I would like to see renewable energy produced for local use in my community/region.), assessed on a Likert-type scale from 1 (strongly disagree) to 10 (strongly agree) based on Rogers et al. (2008).[13] Attitude towards a local community-based renewable energy project (Imagine that a renewable energy project initiated by citizens exists within your community, e.g. an energy cooperative with the objective to produce electricity from renewable sources. In general, how is your attitude towards this project in the field of renewable energies initiated by citizens?) was measured on a Likert scale ranging from 1 (very negative) to 8 (very positive).

Willingness to participate. We measured citizens' willingness to participate in energy projects with two items: First, we asked respondents, if they were willing to volunteer for a community energy project with the objective of collective generation, storage and usage of electricity from renewable sources (In general, how high is your

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[13] All English items and scales were translated to German using the back-translation method (see Brislin, 1970; Shepherd, Kuskova, & Patzelt, 2009).

willingness to invest time in or volunteer for a community energy project?) (see Brayley et al., 2015). Second, financial investment was measured by asking participants, if they were willing to invest financial resources in a community energy project (In general, how high is your willingness to contribute financially and invest money in a community energy project?). Each of the two items was rated using a Likert scale ranging from 1 (very low) to 8 (very high). The two items are strongly correlated (Spearman's rho = 0.801). Hence, we use the average score for the two items to represent willingness to participate in the following.

Community identity. We operationalized community identity – a feeling of attachment to the respective local community – following a scale by van Vugt (2001), that was extended from the community identification and community pride scales of Tyler and Degoey (1995). The three response items ((1) I feel strongly attached to the community I live in. (2) There are many people in my community whom I think of as good friends. (3) I often talk about my community as being a great place to live.) were assessed using 5-point, Likert-type scales from 1 (strongly disagree) to 5 (strongly agree). Together, the three items formed an internally consistent scale (Cronbach's α = 0.809).

Trust. As trust measure we used general trust (Generally speaking, would you say that most people can be trusted, or that you can't be too careful in dealing with people?) from European Social Survey (2012), a standard question applied in many studies and countries (Nannestad, 2008; Uslaner, 2012). This question allows to measure trust on a general level – as opposed to specific trust in community energy. Responses were recorded on a 10-point, Likert-type scale ranging from 0 (You can't be too careful) to 10 (Most people can be trusted). Respondents were also offered a "not applicable / don't know" option. "Don't know" responses were treated as midpoints in the analyses.

Environmental concern. In order to measure the environmental attitude – in particular the extent of environmental concern – we applied the New Ecological Paradigm Scale (Dunlap, Van Liere, Mertig, & Jones, 2000). It contains 15 items (e.g., (5) Humans are severely abusing the environment. (8) The balance of nature is strong enough to cope with the impacts of modern industrial nations. (13) The balance of nature is very delicate and easily upset.) measured on a 5-point, Likert-type scale ranging from 1 (strongly disagree) to 5 (strongly agree). This scale is a revised version of the original New Environmental Paradigm (Dunlap & Van Liere, 1978). The mean of the items (Cronbach's $\alpha = 0.829$) was used to form a composite measure of environmental concern.

Social norms. The operationalization of social norms, as defined above, is based on Hatzl et al. (2014). We adjusted the two-item scale and extended it by one item in order to take peer influence on participation in local energy projects into account; we measure social norms focussing on energy aspects – i.e., renewable energy, energy saving and community energy ((1) Many peers use electricity generated from renewable energy sources. (2) Saving energy is expected by peers. (3) People I care about would approve of my participation in local energy projects.). Answers could be given on a 7-point, Likert-type scale ranging from 1 (totally disagree) to 7 (totally agree). Respondents were also offered a "not applicable / don't know" option. "Don't know" responses were treated as midpoints in the analyses. The reliability of the scale appeared to be sufficient (Cronbach's $\alpha = 0.724$).

Control variables. Gender, age, monthly net household income, type of community and ownership of a renewable energy system were included as control variables.[14] We replaced missing data concerning household income (n = 154; 16.1% of the sample) with predicted values. Income predictions were based on a linear regression including age, gender, household size, education and occupation (Gleason & Staelin, 1975).

3.1.3.3. **Data analysis**

To test the hypotheses, multiple regression analyses and mediation analyses were performed using *IBM SPSS Statistics* version 23. In Step 1 of our conceptual model (continuous lines) multiple regression analyses were undertaken to test H1.1, H2, H3, and H4. Next, in Step 2 (dotted lines) we tested the mediation effect (H1.2, H1.3) using *PROCESS* software by Hayes (2013; see also Preacher & Hayes, 2008). In the mediation model with two mediators the *PROCESS* macro conducts four regression analyses and calculates the total, direct, and indirect effects quantified with unstandardized regression coefficients. Hereby, we are able to determine how the effect

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[14] In the following analyses, net household income is entered as a categorical variable: Household monthly net income (1 = under 900 EUR, 2 = 900 – 1.299 EUR, 3 = 1.300 – 1.499 EUR, 4 = 1.500 – 1.999 EUR, 5 = 2.000 – 2.599 EUR, 6 = 2.600 – 3.599 EUR, 7 = 3.600 – 4.999 EUR, 8 = 5.000 – 6.999 EUR, 9 = 7.000 and more)

of the independent variable X has both a direct effect on the dependent variable Y, as well as an indirect effect on Y through the mediator M. Direct and indirect effects sum up to the total effect (Hayes, 2013).

3.1.4. Results

We report the results of our survey in three parts. First, we present the descriptive statistics. Second, we analyze the effect of community identity, trust and environmental concern on the willingness to participate in community energy. Third, we test the effects of trust and social norms mediating the impact of community identity on the willingness to participate in community energy.

3.1.4.1. Descriptive statistics

We ask, first, what attitude citizens have regarding community energy. As Table 3 reveals, almost 70% of the respondents report a positive attitude towards local production based on renewables, while a share of over 22% is undecided. Only a minor percentage of the population stated a negative attitude. Similarly, the data show a positive attitude towards community-based renewable energy projects of over 60%. However, the share of respondents that are undecided is higher than in the first case.

Table 3: Overview of the attitudes towards local production and community energy

Measures (N = 954)	**Attitudes (in %)** Negative	Undecided	Positive	**Mean**	**SD**	**Scale**
Attitude towards local/regional energy generation based on renewables	8.8	22.4	68.8	7.53	2.41	10-point
Attitude towards community-based renewable energy projects	6.9	31.7	61.4	5.90	1.63	8-point

Source: Own illustration

We analyze if citizens are willing to participate in community energy projects by volunteering or investing financial resources. As Table 4 reveals, over 40% of the sample state a high willingness to volunteer for a community energy project. The share of respondents who reported a high willingness to invest financial resources is lower, with approximately 29%. In both types of participation, a rather large share is more or less undecided. Willingness to volunteer (Mean = 4.81; SD = 2.052; 8-point scale) is higher than their willingness to invest financial resources (Mean = 4.10; SD = 2.201; 8-point scale). The differences between these two types of participation were analyzed with a Mann-Whitney U test, with the result that the willingness to volunteer is significantly higher than the willingness to invest money (Z = -14.726; p < 0.001).

Table 4: Overview of the willingness to participate in community energy projects

Measures (N = 954)	**Willingness (in %)** Low	Medium	High
Willingness to volunteer	24.9	33.4	41.6
Willingness to invest	39.0	31.7	29.4

Source: Own illustration

Correlations between the variables of interest are shown in Table 5. We found a moderate positive correlation between trust and community identity. There is a slightly weaker correlation between social norms and both community identity and trust. Hence, we find positive associations between community identity, trust and social norms. All variables of our conceptual model are significantly related to willingness to participate.

Table 5: Correlation matrix of the community energy study

Spearman's rho	**Community Identity**	**Trust**	**Social norms**	**Environ-mental concern**
Community identity	1.000			
Trust	0.321^{**}	1.000		
Social norms	0.208^{**}	0.170^{**}	1.000	
Environmental concern	-0.005	-0.058	-0.092^{**}	1.000
Willingness to participate (volunteer and invest)	0.179^{**}	0.294^{**}	0.292^{**}	0.156^{**}

Note: ** $p < 0.01$ (2-tailed).

Source: Own illustration

3.1.4.2. Regression analyses

In Step 1 of our conceptual model multiple regression analyses were undertaken. It will be recalled, that community identity, trust, social norms and environmental concern are expected to be positively associated with the willingness to participate in community energy projects (H1.1 H2, H3, H4). Table 6 summarizes the descriptive statistics of variables used in Step 1 and Step 2 of our conceptual model.

Table 6: Descriptive statistics of variables used in the community energy study

Measures (N = 954)	**Mean**	**SD**	**Scale**
Community identity	3.346	0.928	5-point
Trust	5.895	2.554	11-point
Social norms	3.694	1.229	7-point
Environmental concern	3.738	0.558	5-point

Source: Own illustration

According to the R-squares reported in Table 7, the model including all variables explains a substantial share of the variance in the dependent variable. The analysis shows that trust ($\beta=0.195$, $p < 0.001$), social norms ($\beta=0.250$, $p < 0.001$) and environmental concern ($\beta=0.183$, $p < 0.001$) are significantly associated with the willingness to contribute to a community energy project. We find no effect of community identity in the respective model. Hence, our findings provide support for **H2**, **H3** and **H4**, but not for **H1.1**. Furthermore, higher income and being male is found to increase the willingness to participate. It is interesting to note that the suburban, or rural, rather than urban, type of community has predictive value for willingness to participate. Finally, ownership of a renewable energy system contributes positively to the prediction of willingness to participate in community energy.

Results from our simplified model show that community identity has a significant positive effect on the willingness to participate, when trust and social norms are excluded from the regression. Community identity is an order of magnitude bigger in the simplified model, while the other variables are constant as regards the size and significance of the effect.

Overall, social norms are found to have the highest impact on the willingness to engage in community energy projects, followed by trust and environmental concern. Besides, income and ownership of a renewable energy system are among the main factors influencing willingness to participate – while community identity is found to interact with trust and social norms.

Table 7: Parameter estimates for the regression analyses

	Unstandardized Coefficients			**Standard. Coefficients**	**Unstandardized Coefficients**			**Standard. Coefficients**
	B		Std. Error	Beta	B		Std. Error	Beta
Community identity	0.303	***	0.067	0.139	0.060		0.067	0.028
Environmental concern	0.564	***	0.108	0.156	0.662	***	0.102	0.183
Trust	-		-	-	0.154	***	0.024	0.195
Social norms	-		-	-	0.411	***	0.049	0.250
Gender (female = 1)	-0.479	***	0.123	-0.118	-0.473	***	0.116	-0.117
Age	-0.009	*	0.004	-0.068	-0.004		0.004	-0.030
Net household income	0.195	***	0.033	0.183	0.159	***	0.031	0.149
Type of community (suburban/rural=1)^{a}	0.275	*	0.122	0.068	0.248	*	0.115	0.061
Ownership of renewable energy system (owner=1)	0.908	***	0.161	0.174	0.692	***	0.152	0.133
(Constant)	0.694		0.500		-1.300	*	0.504	
	Adjusted R Square 0.164				Adjusted R Square 0.263			

Dependent Variable: Willingness to participate in a local community energy project;
Notes: $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$; ^{a} Urban=0; suburban or rural=1

Source: Own illustration

3.1.4.3. **Mediation analyses**

Next, in Step 2 of our analysis, we conducted mediation analyses to test whether the effect of community identity on the willingness to participate in community energy projects is mediated by changes in trust and social norms. We tested for mediation using Preacher and Hayes's (2008) procedure (*PROCESS* macro, Model 6). As Table 8 reveals, the bootstrapping tests showed that, after controlling for the socio-demographic variables, the indirect effect of community identity on willingness to participate through trust is positive and significant (indirect effect = 0.1306, 95% CI = [0.0801, 0.1831]), as is the indirect effect through social norms (indirect effect = 0.0901, 95% CI = [0.0491, 0.1395]). The direct effect became non-significant when the mediators were included in the model (direct effect = 0.0605, p = 0.3649). Thus, as we expected, community identity influences willingness to participate in community energy, and this effect occurs through changes in trust and social norms. Therefore, **H1.2** and **H1.3** are supported. The findings show that trust and social norms fully mediate the relationship between community identity and willingness to participate.

Table 8: Results of the mediation analysis with *PROCESS*

Exogenous variable	**Mediator**	**Endogenous variable**	**Coeff. b**	**Coeff. b**	**Effect**	**BC bootstrap 95% CI**	
(X)	*(M)*	*(Y)*	*(X → M, a)*	*(M → Y, b)*	*(a × b)*		
Community identity	Trust	Willingness to participate	0.849^{***}	0.154^{***}	0.131 (indirect)	0.080	0.183
Community identity	Social norms	Willingness to participate	0.219^{***}	0.411^{***}	0.090 (indirect)	0.049	0.140
Community identity		Willingness to participate			0.061 (direct)	-0.070	0.191

Note: *** $p < 0.001$; Control variables were environmental concern, age, gender, net household income, type of community and ownership of renewable energy system. The indirect effect of community identity on willingness to participate through trust and social norms as simultaneous mediators is presented in Appendices 1 and 2.

Source: Own illustration

3.1.5. Conclusion

In this paper, we set out to acquire a better understanding of citizen participation in community energy. We introduced and tested a conceptual framework focusing on community identity, trust, and social norms. The attitudes towards local generation of green electricity and community energy projects have been shown to be positive in large parts of the German population. However, a rather large percentage of the sample was undecided in regards to the attitude towards community energy. Willingness to volunteer is higher than willingness to invest financial resources. We find a rather high proportion of respondents with a moderate willingness to participate. Community identity, trust, social norms – peers' expectations as regards energy issues – and higher environmental concern are positively associated with the willingness to participate, i.e. volunteer or invest financial resources, in community energy projects. The reported analyses show that social norms and trust have the strongest associations with the willingness to participate, followed by environmental concern and higher income. Community identity represents one of the weaker predictors of participation in our study. Social norms and trust were found to fully mediate the effect of community identity on the willingness to participate. Ownership of a renewable energy system and living in a suburban, or rural, rather than urban, community increase the likelihood of participation.

We address the research gap on trust (Greenberg, 2014) and social norms (Rogers et al., 2012) as regards community energy and contribute to research on community energy and citizen participation. Furthermore, we inform the wider field of pro-environmental behavior in particular those related to community-based initiatives. The paper revealed the relevance of socio-psychological aspects like trust and social norms to determine willingness to participate in community energy apart from the influence of environmental concern. Moreover, we found a positive effect of community identity on the willingness to participate through changes in general trust and social norms.

The positive attitudes and the large share of respondents willing to participate in community energy found in our study seem to provide support for local energy projects. This indicates the interest in and the potential of community-based energy solutions. In our study we only assessed willingness to participate, however, participation in pro-environmental action, e.g., community energy, is generally low (Bomberg & McEwen, 2012). An intention-behavior gap has been frequently observed (Fennis, Adriaanse, Stroebe, & Pol, 2011; Ozaki, 2011; Webb & Sheeran, 2006). Hence, it has to be kept in mind that we assessed an intention and not actual behavior when interpreting the results. Analyzing actual behavioral data on citizens' participation in community energy or similar projects, would allow for an advanced analysis of our conceptual model.

Participation in community energy is promoted by community identity and contacts at the local neighborhood level (Hoffman & High-Pippert, 2010) and can facilitate a sense of community (Bekkers, 2012) – which could again reinforce participation. Earlier studies have found that trust supports citizen participation, and its importance in community energy as both a prerequisite and outcome have been emphasized (Walker et al., 2010). In fact, a higher level of trust seems to promote participation in community energy. In line with earlier research, we confirm the relevance of trust and community identity. However, community identity only has a positive indirect effect on willingness to participate through social norms and trust. Hence, we find an influence of expectations of peers and general trust that mediate the effects of community identity, and highlight the importance of trust and social norms as a determining factor of willingness to take part in community energy. Moreover, community energy projects have the potential to *foster new social norms* (Rogers et al., 2012, p. 240) regarding renewable energies and local community-based generation. Findings on the effect of urban versus rural residence on pro-environmental behavior vary (Gifford & Nilsson, 2014). In our study we find that a community characterized as suburban, or rural, rather appears to predict participation. Different models of participation and ownership, being more or less inclusive (Walker, 2008), could be offered to increase participation in rather urban areas.

The findings can improve the initiation and successful operation of community projects, in particular by taking into account the effects of trust, social norms and environmental concern. They also highlight the important role of community identity as an antecedent. This not only helps to advance the concept of community energy, but also the development of effective planning policies and communication strategies. The positive attitudes found in this study could be a starting point to further increase the share of renewables owned and managed by community-led initiatives. Local engagement, sustained participation and financial resources as well as expertise and governmental support are needed for the mobilization and success of community energy (Bomberg & McEwen, 2012; Mulugetta et al., 2010). Policy-makers can use our insights to set an appropriate framework (Mulugetta et al., 2010). Policies aimed to promote community energy and participation should focus on lowering the costs and barriers to engage in community energy – taking into account the relevance of trust and social norms. Educating and informing citizens about community energy could lay the foundations for active participation. Sustained participation could be achieved by offering community and personal benefits (Hoffman & High-Pippert, 2010). An increased rate of participation could potentially transform community energy initiatives in Germany from a niche to a more mainstream scheme (Geels & Kemp, 2007). In addition, our findings can help policy-makers to support particular communities or projects.

Involving citizens as investors or volunteers can be an important means to support local energy transition projects. The projects should take the importance of social aspects into account to motivate citizens to invest either their financial or temporal resources. Due to the relevance of social norms, a social norms marketing approach could be implemented. This approach could be used as a means to influence citizens' social expectations and foster participation in community energy projects (Burchell, Rettie, & Patel, 2013; Fisher & Ackerman, 1998; Thøgersen & Grønhøj, 2010), by creating a *salient social pressure* (Storey, Saffitz, & Rimón, 2008, p. 447). Individuals involved with community energy projects or influencers such as opinion leaders within the communities could use this means to promote community energy.

The findings can also help to initiate community energy projects and similar initiatives in countries other than Germany. Although the determinants might differ in their effect size, community identity, social norms, trust and environmental concern can be essential building blocks in initiating new projects. Additionally, we recommend the consideration of trust and social norms as potential influences when recruiting members or financial resources. Other types of similar initiatives or movements, e.g. environmental organizations or local fundraising campaigns, could as well benefit from our findings. Furthermore, our results can be incorporated by policy-makers to set a framework or support schemes in countries where community energy is not established yet.

Several limitations of our study need to be considered. Willingness to participate items were rather ambiguous, as they lacked detailed information on the community energy project; especially for the willingness to invest financial resources information on risk and return could have led to a more realistic setting. However, we kept this in mind when designing the questionnaire. In order to simplify the question and analyze the general willingness to invest, we decided on a simple and general measure. In the present study, willingness to participate in community energy projects was measured with a two-item scale including volunteering and investing financial resources in a community energy project. Future research may benefit from examining different types of participation and investment in detail. Other explanatory variables could have been included in our analysis. Risk and uncertainty are important parameters for the concept of trust (Hartmann, Klink, & Simons, 2015). Further studies could, for example, include measures on specific trust in community energy or on the readiness to assume risk. The study was conducted in Germany, a forerunner in the transition towards an energy system based on renewables (Bomberg & McEwen, 2012; Yildiz et al., 2015). Taking into account the specific settings, results may be transferred to other countries and types of projects. Further research could compare members and non-members of community energy projects, or focus on initiators of community energy projects. Research on the founding stage of community energy projects and the willingness to act as a project leader (Rogers et al., 2008) would help to further advance the understanding of community energy with respect to the local conditions.

Energy transitions are economic and technological, but also social and political transformations (Miller et al., 2015). We contribute to the research on energy transitions as a societal phenomenon. This study helps to understand the principles underpinning the willingness to participate in community energy. Our insights extend literature on collective pro-environmental action and emphasize the importance of social, rather than merely environmentally motivated, aspects for community energy projects. Our study shows that, regarding community energy, the relevance of trust and social norms cannot be ignored. Overall, the study underlines the acceptance and potential of community energy projects and shows factors that influence citizens' willingness to participate that were previously unknown. Knowing the relevant factors that determine willingness to participate can help to enhance the understanding of community energy schemes and pro-environmental behavior.

3.2. Innovation for a sustainable energy system – Customer-focused business models for battery storage systems *(ESSAY II)* [15]

Abstract

A decarbonized energy system is a key challenge on the path towards sustainability. To achieve a sustainable energy system, a solution to the intermittency of renewable energy sources is needed. Battery storage systems are promising, but still expensive technologies. Innovative business models can improve economic factors and customer value, and foster the diffusion of such systems. However, there is a lack of understanding on how to design appropriate business models for storage systems. This paper explores key business model components focusing on consumer preferences for different battery storage configurations. Our empirical analysis samples German adopters of a photovoltaic system and interested non-adopters (N=836). In a choice experiment respondents had to choose among different battery storage systems. We estimate a mixed logit model and present willingness to pay estimates for the business model components. Potential for the residential and community storage concept with joint usage is found. High levels of autarky have a high utility for consumers. Consumers

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[15] *Essay II* is based on Kalkbrenner, B. J., Roosen, J., 2016. Collaborative Consumption in Energy Issues – PV-owners' Preferences for Residential vs. Community Battery Storage Systems. Paper presented at the International Association for Energy Economics (IAEE) International Conference in Bergen, Norway (June 20, 2016).

Bernhard Kalkbrenner designed the study, performed the analyses and wrote the paper. Jutta Roosen provided advice on the development of the study and editorial input.

favor ownership over use rights and are willing to give up control to provide services for the grid. Market opportunities for regional power providers, cooperatives, and new market entrants are found. Hence, possibilities for collaborative business models and resource sharing in the energy sector exist.

Keywords: Autarky, business model, choice analysis, energy storage, renewable energy, resource sharing

3.2.1. Introduction

A clean and affordable energy system is crucial to combating climate change and assuring sustainable consumption and production (European Parliament, 2014; United Nations, 2015). Sustainable energy systems involve renewable energy sources, such as wind and solar, that are characterized by a lack of temporal and spatial consistency (Khalilpour & Vassallo, 2015). Battery storage systems can offset this intermittency, facilitate the integration of electricity from renewable sources, and enhance decarbonization and sustainability (Agnew & Dargusch, 2015; De Sisternes et al., 2016).

Storing electrical energy in batteries is still expensive. However, present and expected reductions in the prices of battery storage systems (Koirala et al., 2016) and photovoltaic (PV) systems (Parra & Patel, 2016) create excitement in the industry (Khalilpour & Vassallo, 2015). Rising electricity prices also improve the profitability of battery storage (Agnew & Dargusch, 2015), promoting the diffusion of combined PV and battery systems (Parra & Patel, 2016).

Numerous studies investigate energy storage systems (Aneke & Wang, 2016; Cucchiella et al., 2016; Golembiewski, Vom Stein, Sick,

& Wiemhöfer, 2015). Although discussions regarding their economic viability are ongoing and uncertainty regarding price reductions persists, they potentially are sustainable innovations (see Boons & Lüdeke-Freund, 2013). Rising demand for battery storage systems—Germany installed around 20,000 systems in 2015—illustrates that consumers are attracted despite high prices (Kairies et al., 2016). Declining governmental funding for PV systems compels the creation of new routes for sustainable energy technologies (Hagerman et al., 2016). A shift from ownership to access and collaborative business models with different actors involved have been proposed to overcome risks, high prices, and other barriers to adoption (Engelken, Römer, Drescher, Welpe, & Picot, 2016; Niesten & Alkemade, 2016; Römer et al., 2012; Verbong et al., 2016).[16] The deployment on the community scale, instead of the household scale, as well as the combined use of multiple applications (Malhotra, Battke, Beuse, Stephan, & Schmidt, 2016; Stephan et al., 2016), can provide further benefits and financial gains. Studies generally show support for community-based energy projects (e.g., Kalkbrenner & Roosen, 2016). Verbong et al. (2016) highlight the role of *user-centered business models* for the smart grid. Such models may drive the diffusion of new technologies (Boons & Lüdeke-Freund, 2013; Zott, Amit, & Massa, 2011).

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[16] Collaborative business models are characterized by the co-operation of *multiple organizations that might differ in type (industry, public research and non-profit), their position in the value chain (manufacturing, service, etc.) and industry (energy, ICT, etc.) (…) to create a value creation system* (Rohrbeck, Konnertz, & Knab, 2013, p. 8). In this dissertation, the term comprises co-operation of multiple actors such as households, community energy projects and energy companies.

To encourage diffusion and adequate regulation of storage systems, it is important to analyze business model components and consumers' attitudes and preferences. However, consumers' preferences for storage systems and willingness to pay remain unspecified. Earlier studies mainly examine the technical aspects of energy storage, and few empirically analyze consumers and business models (see also Rae & Bradley, 2012). To our knowledge, no empirical study examines consumer preferences for different concepts of battery storage and collaborative business models. This paper addresses these gaps and explores consumer preferences for battery storage systems and customer-focused business models in a choice experiment.

The study builds on a framework inspired by Walker & Cass (2007) to investigate key aspects for battery storage business models, and aims at examining consumer preferences and business models by analyzing implementation concepts, economic factors, ownership modes, energy autarky, control and provision of grid services, and types of partner companies. The study's results can assist in creating customer-focused business models, designing product service systems (see Annarelli, Battistella, & Nonino, 2016), diffusing storage systems, and assessing potential for technologies and policy instruments.

The paper proceeds as follows. *Section 3.2.2* presents background, the business model components, and hypotheses. *Section 3.2.3* introduces our methodological approach and design of the discrete choice experiment. *Section 3.2.4* presents and discusses results. *Section 3.2.5* suggests the study's implications.

3.2.2. Background

3.2.2.1. Business models

Appropriate business models are crucial in today's market environment (Desyllas & Sako, 2013). This holds particularly true for the adoption and diffusion of technological innovations (Chesbrough & Rosenbloom, 2002; Johnson, Christensen, & Kagermann, 2008). Business models offering appropriate financing, cooperative forms or combined applications can be viable solutions for high-cost battery storage deployment (see Agnew & Dargusch, 2015). Business models consist of value proposition, a value creation and delivery system, and value capture (Richardson, 2008; Teece, 2010). A business model for sustainable development *creates competitive advantage through superior customer value and contributes to a sustainable development of the company and society* (Lüdeke-Freund, 2010, p. 23). The value customers assign to an innovation is the core of a business model (Chesbrough & Rosenbloom, 2002) and the focus of this paper.

3.2.2.2. Battery storage systems

Decentralized generation and implementation of battery storage systems could transform the electricity system (Khalilpour & Vassallo, 2015) and alter the economics of renewable energies (Difiglio, 2016; Trancik, Brown, Jean, Kavlak, & Klemun, 2015). Falling prices for PV systems and battery storage technology alongside rising household electricity bills foster diffusion of storage systems (Kempener & Borden, 2015; Linssen, Stenzel, & Fleer, 2017; Nykvist & Nilsson, 2015), but technological, regulatory, and market uncertainties persist (Malhotra et al., 2016). Technical and economic improvements in storage technologies are needed to achieve their full potential (Barnhart & Benson, 2013). Since the battery storage market is young (Malhotra et al., 2016), no dominant technology or configuration has emerged. However, lithium-ion and lead-acid batteries are the main technologies for residential applications (Linssen et al., 2017). Lithium-ion batteries are expected to dominate the market (Eller & Dehamna, 2016). In Germany, 3 out of 4 storage systems installed are lithium-based (Appen & Braun, 2015).

Battery storage systems presently are unprofitable (Cucchiella et al., 2016; Graditi et al., 2016) and high costs hamper their diffusion (Khalilpour & Vassallo, 2015). However, lithium-ion systems exhibit a steeply declining price trajectory alongside performance improvements (Armstrong et al., 2016; Nykvist & Nilsson, 2015). In Germany, the average price of lithium-ion batteries has fallen 39%, and around 34,000 battery storage systems were installed between 2013 and 2016 (Kairies et al., 2016). In 2015, almost half the small PV systems installed in Germany had a battery storage system (Kairies et al., 2016).

Different concepts of battery storage systems can include residential (RBS) or community-based battery systems (CBS) with joint usage. Although residential battery systems are the most common in on-grid applications, CBS could offer benefits for grid operation and economic gains (Zeh, Rau, et al., 2016), fostering their diffusion.

A wide range of use cases exist for battery storage systems (Malhotra et al., 2016). Electricity price arbitrage is a key value proposition (De Sisternes et al., 2016). Storage systems can increase self-consumption and autarky for consumers (Gährs et al., 2015;

Graebig, Erdmann, & Röder, 2014). They can enhance transmission and distribution of electricity (Parra et al., 2016), stabilize fluctuations in power generation (Armstrong et al., 2016), provide frequency or voltage control (Akorede et al., 2010), enhance peak-shaving (Passey et al., 2011) and defer upgrades and infrastructure replacement for distribution network operators (Parra et al., 2016; Yunusov, Frame, Holderbaum, & Potter, 2016).

3.2.2.3. Consumers' motivations to purchase battery storage systems

Consumers are interested in storage solutions even though they presently are not cost-effective (Linssen et al., 2017). Hence, storage systems seem to offer a value besides economic profit. Several scholars have analyzed consumers' motivations to buy battery storage systems mainly focusing on Germany (Gährs et al., 2015; Galassi & Madlener, 2014; Graebig et al., 2014; Kairies et al., 2016; Kairies, Magnor, & Sauer, 2015; Römer et al., 2014). German consumers identify financial benefits from self-consumption and protection against rising electricity prices as their motives for installing battery systems (Graebig et al., 2014). They rank self-sufficiency as a close second. High levels of autarky are important (Balcombe, Rigby, & Azapagic, 2014; Oberst & Madlener, 2015). Kairies et al. (2015) list hedging against rising electricity prices and contributing to energy transition as primary motivations, followed by technological interest. Gährs et al. (2015) find that PV owners in Germany value independence from power providers, whereas financial return is irrelevant. Barriers to purchasing battery systems are high investment costs and risks, e.g. uncertainty about the lifetime of the system (Gährs et al., 2015). Economic considerations and autarky head the motivations for investing in storage systems.

3.2.2.4. Framework and hypotheses

Framework of the study

This study aims at analyzing relevant business model components for battery storage systems in a choice experiment. The design of the choice experiment builds on a model by Walker & Cass (2007), and is also inspired by Huijben and Verbong (2013), and Sauter and Watson (2007). As Figure 8 shows, our framework consists of technology, economic factors, an implementation concept, ownership mode, autarky, control and grid services, and a partner company.

Figure 8: Framework for analyzing battery energy storage systems

Technology	**Economic factors**	**Implementation concept**	**Ownership mode**	**Autarky**	**Control and grid services**	**Partner company**

Source: Own illustration inspired by Walker and Cass (2007)

The first component—technology—is defined as storage systems based on lithium-ion batteries. In the following, we present the operationalization of the other parameters of the framework for the choice experiment.

Choice attributes

Based on our conceptual framework we examine business model components for battery storage systems and derive hypotheses.

Economic factors. Adoption of renewable energy technology is hindered by high investment costs (Balcombe et al., 2014; Scarpa & Willis, 2010). Financial costs and benefits are crucial to investment in battery storage systems (Kempener & Borden, 2015). Present storage systems based on lithium-ion batteries are expensive (Battke, Schmidt, Grosspietsch, & Hoffmann, 2013; Carbajales-Dale, Barnhart, & Benson, 2014). Since the relationship between investment costs and product choice is inverse (Achtnicht & Madlener, 2014), we propose Hypothesis 1a:

Hypothesis 1a. Consumers prefer lower-costs battery storage systems.

Rai and Sigrin (2013) identify payback period as another important financial criterion for investing in PV systems. Usually, the payback period is uncertain and depends on such factors as energy price development and interest rates. Studies of housing and renewable energy show that short payback periods are crucial for adoption (Achtnicht & Madlener, 2014; Sauter & Watson, 2007; Sonnberger, 2014). Therefore, we propose Hypothesis 1b:

Hypothesis 1b. Consumers prefer short payback periods when investing in battery storage.

Implementation concept. Among battery systems, residential and community systems are end-user applications (Parra et al., 2015). Residential battery systems currently dominate the market (Kairies, Magnor, et al., 2015). Other systems have been tested such as community battery systems (see Griese, Wawer, & Böcher, 2016; Parra et al., 2016). RBS are installed in the end-user's home and usually have up to 20 kWh (Parra et al., 2015). Residential systems allow increased self-consumption of electricity (Kairies, Magnor, et al., 2015) and can aid time- and load-shifting (Parra et al., 2015, p. 578). They can be connected to other residential systems to provide grid services such as primary frequency control (Schopfer, Tiefenbeck, Fleisch, & Staake, 2016). CBS are larger systems in the range of 10 to 100s of kWhs located in the community and connected to multiple households (Parra et al., 2015, 2016). They, for instance, allow groups of consumers to collectively own shares of a storage system. CBS serve end-users and operators of distribution systems (Parra et al., 2016). While RBS usually are located indoors, CBS are placed outdoors (e.g., in a cargo container (Jossen et al., 2015)). Parra et al. (2015, 2016) identified economic advantages of up to 37% for CBS over RBS as well as technical benefits, e.g. regarding the discharge rates and higher round trip efficiencies. To conclude, energy projects on the community level can have technical and financial benefits over individual implementation such as higher efficiency and lower investment costs for the individual (Huijben & Verbong, 2013).

Safety of storage systems is an important issue (Kempener & Borden, 2015; Roskilly, Taylor, & Yan, 2015). Although Gährs et al. (2015) find that safety concerns did not impede adoption, burning batteries could be perceived as a safety risk (Jacoby, 2007; Ping et al., 2015). Safety concerns might be diminished if storage systems are located outside end-users' homes. Because economic benefits and lessened safety concerns might incentivize community-based over residential systems, we propose Hypothesis 2:

Hypothesis 2. Consumers prefer community storage systems over residential systems.

Ownership mode. Scholars and industry are prioritizing new usage modes and sharing business models (Martin, 2016). Bocken et al. (2014) present *functionality, rather than ownership* as an archetype of sustainable business models. Function-oriented business models, product service systems, or third-party-ownership are relevant for energy and housing (Boons et al., 2013; Overholm, 2015; Tukker & Tischner, 2006), but new to the storage market.[17] Ownership is the dominant mode for storage systems. Since high investment costs hinder adoption of energy technology (Balcombe et al., 2014; Scarpa & Willis, 2010), however, non-ownership modes can be valuable, particularly during the early stages of diffusion (Rai & Sigrin, 2013). Galassi and Madlener (2014) find support for leasing and non-ownership of PV and battery systems in Italy, as do Rai and Sigrin (2013) for PV systems in the USA. Lower investment costs and lower technological uncertainties drive such models (Rai & Sigrin, 2013). Some studies report consumer preferences for ownership of storage systems, e.g in Germany (Graebig et al., 2014), but results are ambiguous. We propose Hypothesis 3:

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[17] Product service systems are *a mix of tangible products and intangible services designed and combined so that they jointly are capable of fulfilling final customer needs* (Tukker & Tischner, 2006, p. 1552; see also Tukker, 2015).

Hypothesis 3. Consumers prefer ownership of battery storage systems over use rights.

Autarky. Independence is among the main reasons to adopt PV systems (Claudy et al., 2013) and battery storage systems (Gährs et al., 2015). Strong preferences exist for self-consumption of energy generated, although it is neither the most cost-efficient nor sustainable solution (Wiekens, 2016). An increasing number of studies examine energy autarky (Engelken, Römer, Drescher, & Welpe, 2016; McKenna, Herbes, & Fichtner, 2015; M. O. Müller, Stämpfli, Dold, & Hammer, 2011). The level of autarky is described as *how much of the load demand can be covered by the local (…) generation* (Merei, Moshövel, Magnor, & Sauer, 2016). Oberst and Madlener (2015) find strong preferences for high autarky (80%–100%). Autarky is a rather psychological phenomenon (Khalilpour & Vassallo, 2015). High levels of self-sufficiency are possible by combining PV and battery storage systems, full autarky requires economically unsound investment, particularly in battery technology (Khalilpour & Vassallo, 2015). Nevertheless, present market developments foster energy autarky and consumption of locally generated electricity (Kempener & Borden, 2015; Linssen et al., 2017). The literature review suggests Hypothesis 4:

Hypothesis 4. Consumers prefer high levels of energy autarky.

Control and grid services. Control and automation of storage systems are relevant issues in business models because they can serve the power grid. A partner company may be granted permission to control battery charging and discharging to provide services to the grid (Parra et al., 2015). Such services can benefit users and operators of storage systems financially (Agnew & Dargusch, 2015). However, Karjalainen (2013) finds that consumers wish to control appliances and distrust automation in Finland. Control—either an opt-in option or ability to *override the system* (Buchanan, Banks, Preston, & Russo, 2016, p. 95)—seems highly desired among end-users (Raimi & Carrico, 2016). Business models that wrest control from consumers are unlikely to be accepted. However, Gallassi and Madlener (2014) find that adopters of combined PV and storage systems in Italy favor external control and maintenance by utility companies. In the Netherlands, Wiekens (2016) finds preferences for automatic and semi-automatic control (with a manual option) for demand side management. Although findings are ambiguous, we propose Hypothesis 5:

Hypothesis 5. Consumers want to control their storage system but will relinquish some control to provide grid services.

Partner company. A partner company can have permission to control and maintain a storage system. Rommel et al. (2016) and Sagebiel et al. (2014) find that consumer preferences depend on the type of provider and vary from regional to nationwide providers. They show that preferences for municipal power providers and cooperatives exist. Opportunities exist for small enterprises (van Vliet, 2012, p. 265) and intermediaries (Marvin & Medd, 2004; Overholm, 2017).

Trust is central to smart energy systems (Buchanan et al., 2016; Wiekens, 2016), and power companies enjoy little trust (Gangale, Mengolini, & Onyeji, 2013; Goulden et al., 2014). However, Raimi and Carrico (2016) report preferences for power providers and against third parties. This might be based on *distrust* of third-party providers (Raimi & Carrico, 2016, p. 72). We expect that end-users prefer established players such as nationwide or regional energy providers. We propose Hypothesis 6:

Hypothesis 6. Consumers prefer well-established companies over new entrants as partners for control and maintenance of storage systems.

3.2.3. Methodological approach

3.2.3.1. Methods

We empirically investigate business model components for battery storage systems using a discrete choice experiment in which survey participants had to hypothetically choose among different battery storage systems. Each respondent was presented eight choice scenarios – each characterized by three different storage configurations and a none-option, i.e. the option to choose none of the presented systems. We included a none option for realism (Hensher, Rose, & Greene, 2015). Table 9 reveals the choice design and the table in Appendix 3 indicates a sample task. Per our conceptual framework, choice scenarios embody six attributes: implementation concept (RBS – in house, CBS – in neighborhood), economic factors (costs and payback period), mode of ownership, degree of autarky, control and provision of grid services, and type of partner company implementing the battery storage solution. In order to compare ownership and usage right models, we use a nested design for cost and payback period depending on the usage right.

Table 9: Attributes and levels used in the storage choice experiment

Attributes	Levels			
Location of the storage system	In your house* *(RBS)* [a]	In your neighborhood *(CBS)* [a]		
Cost (in Euro)	One-time payment: [b]			
	€6,000	€9,000	€12,000	€15,000
	Monthly fee for 10 years: [c]			
	€45	€65	€85	€110
Ownership mode	Ownership	Use rights*		
Payback period	*None* [c]	6 years	12 years	18 years
Average level of autarky	25%*	50%	75%	100%
Control & provision of grid services	Own control	Own control by default	External control by default	External control by partner companies*
Partner company (e.g. maintenance and control)	Nationwide electricity supplier	Regionally based electricity supplier	Regionally based energy cooperative	Battery operator*

Note: * Reference level in the data analysis; [a] Labels not shown in the choice cards; [b] in case of ownership; [c] in case of use right

Source: Own illustration

Implementation concept. We analyze residential and community storage systems. The choice sets distinguish concepts by location. Systems can be located either *"in your house"* (RBS) or *"in your neighborhood"* (CBS).

Cost, payback period and ownership mode. The attributes cost, payback period, and mode of ownership are interconnected. We specify two modes of payment: upfront payment and a monthly fee. A one-time investment implies ownership; monthly payments grant use rights. The mode of payment determines the payback period. We displayed payback periods for one-time payments only, as monthly payments represent fee-based usage for 10 years with no specific payback period. To test preferences for modes of ownership, we include two levels: ownership or use rights. Use rights were not specified further. We specify 6-, 12-, and 18-year paybacks for one-time investments based on studies of battery and PV systems (Kempener & Borden, 2015; Sonnberger, 2014). No payback period was indicated in the use rights scenarios. Costs are the average for battery storage systems in Germany with a capacity between 6 and 7 kWh (Kairies, Magnor, et al., 2015) and average costs for lithium-ion systems ranging from 1,300 €/kWh to 2,000 €/kWh (Linssen et al., 2017). At the start of 2016, prices were as low as €1,000 to €1,200 (Kairies et al., 2016). To account for a range of costs, we fixed four levels of one-time payments: €6,000, €9,000, €12,000, and €15,000. For the monthly fee, we included €45, €65, €85, and €110 per month for 10 years. The 10-year period is from similar studies by Graebig et al. (2014) and commercial practice (DZ-4, n.d.), product life might reach 20 years (Lewis, 2016). Net present value of monthly fees approximates 75% of the corresponding one-time payment at an interest rate of 3.1% (Graebig et al., 2014). Monthly payments over the 10 year period, hence, correspond approximately to one-time payments.

Autarky. The autarky attribute was described as the share of electricity that respondents can consume over a year using a combined PV and storage system. Ranges of autarky are 25%, 50%, 75%, and 100%. Although 85% is feasible (Loges, Bunk, & Engel, 2014), levels above 65% are rare in Germany (Kairies et al., 2016; Kairies, Haberschusz, et al., 2015). We included 100% autarky, as earlier studies find preferences for high levels of autarky.

Control and grid services. We proposed control levels that range from own control to complete external control of the storage system. These attributes also indicate willingness to support the grid. We took into account different default settings. Options are *own control* (end-user has full control, no external control and grid services), *own control by default* (end-user has control but can switch on external control and grid services for a time), *external control by default* (partner company has external control, but end-users can deactivate for certain periods), and *external control* (partner company has full external control). For realism, the control attribute for CBS could only be *external control by default* or *external control.*

Partner company. Partner companies control and maintain storage systems. Choices were a nationwide electricity supplier (e.g., E.ON, Lichtblick), a regional electricity supplier (e.g., municipal utility), a regional energy cooperative with citizen participation on a municipal and regional level, or a specialized battery operator (e.g., Sonnen, Tesla, Caterva). We specified those choices per Kaenzig et al. (2013) and Rommel et al. (2016) as extended to the context of energy storage.

We generated an efficient design that minimizes the d-error using the software package *Ngene*. We chose a fractional design with constraints imposed – as described above. Our final design yielded 16 choice sets, blocked into two equal-sized blocks. As an introduction to the choice experiment we presented detailed information about the choice decisions and included a cheap talk script to remind participants of their budget constraint (see Lusk, 2003).

3.2.3.2. **Data collection**

We conducted an online survey in Germany during March and April 2016. Sampling proceeded in three ways. First, a professional market research company interviewed owners of PV systems. Second, we contacted owners of PV systems in collaboration with two PV associations. Third, we posted a link to the survey on a PV Internet forum. Respondents had an opportunity to enter a lottery for either a shopping voucher (€25, €50, and €75 four times each) or donating the amount to a charity to encourage full completion of the questionnaire. A total 936 respondents completed the online questionnaire.[18] Data cleaning proceeded in two steps. First, we excluded from analysis frivolous participants based on age and respondents who finished in fewer than 10.88 minutes (1SD below the mean). Second, we double-checked responses with a duration between 10.88 and 15 minutes for inconsistencies. The final sample contained 836 respondents who had

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[18] We excluded non-adopters of a PV system that had a low interest in both PV and battery systems (filter question). The sample consists of 307 respondents from the market research institute and 629 from the associations and internet forum.

adopted a PV system (n=752) or were non-adopters who were interested in PV and battery storage systems (n=84).

3.2.3.3. Statistical model and data analysis

Our stated preference method is based on McFadden's (1974) random utility framework, which postulates that consumers choose the alternative from a set of alternatives that maximizes their utility. Different models with specific assumptions can be applied to analyze choice data (Train, 2009). Multinomial logit is frequently used. We tested for the assumption of independence of irrelevant alternatives (IIA) of the multinomial logit model using the Hausman test and found the assumption does not hold (Hausman & McFadden, 1984). We, hence, estimated a mixed logit model, which allows for preference heterogeneity (McFadden & Train, 2000; Revelt & Train, 1998). We operationalized the random utility framework as follows. The utility U_{ijt} of individual i provided by alternative j (a specified battery storage system) in choice situation t is assumed to be:

$$U_{ijt} = \beta^0 COST_{ijt} + \sum_{k=1}^{K} \beta_i^k X_{ijt}^k + \epsilon_{ijt} \qquad (1)$$

$$\beta_i^k = \bar{\beta}^k + \theta_i^k, \theta_i^k \sim N(0, {\sigma_k}^2) \qquad (2)$$

where β^0 and β_i^k ($k = 1 \cdots K$) are the parameters to be estimated, $COST_{ijt}$ is the cost of the battery system and X_{ijt}^k is the kth non-cost attributes of alternative j in choice situation t. Here, ϵ_{ijt} represent the unobserved random error components. All coefficients are randomized except cost and the none option, which we specify to be fixed (Hole & Kolstad, 2012). The error term ϵ_{ijt} is assumed to be independently and identically distributed (iid). Hence, the probability of respondent i choosing choice alternative j in choice situation t is given by:

$$P_{ijt} = \int \cdots \int \frac{\exp(\beta_i^0 COST_{ijt} + \sum_{k=1}^{K} \beta_i^k X_{ijt}^k)}{\sum_{j=1}^{J} \exp(\beta_i^0 COST_{ijt} + \sum_{k=1}^{K} \beta_i^k X_{ijt}^k)} dF(\theta_i^1) \cdots dF(\theta_i^K), \qquad (3)$$

where $F(\cdot)$ is the cumulative standard normal distribution and θ_i^k are normally distributed. The latter account for unobserved heterogeneity in the marginal utility. The estimation of equation (3) requires a simulated maximum likelihood approach since the function does not have a closed form (Train, 2009). We use Halton draws with 500 replications for maximizing the log-likelihood function (Hole, 2007). The model is estimated with *Stata 13* using the *mixlogit* command. Willingness to pay estimates are calculated as the negative ratio of the attribute parameter to the cost parameter (Train, 2009):

$$WTP = -\frac{\beta_i^k}{\beta^0} \qquad (4)$$

We apply hybrid coding to the choice data (Cooper, Rose, & Crase, 2012; Hensher et al., 2015), where cost and payback period are coded as continuous variables. Cost for monthly payments are translated into net present value as explained in *Section 3.2.3.1* and enter the estimation as cost variable together with single payment for ownership.

3.2.4. Results and discussion

3.2.4.1. Descriptive results

Among our 836 respondents, 90% own a PV system (n=752) and 10% are interested non-adopters (n=84). Table 10 gives an overview of the sample characteristics. Respondents were predominantly male, older than 40 (18.2% were 40–49; 66.4% were 50 and older), well-educated (51.8% held a degree), and had high household income. The sample is not intended to be representative of the German population, but rather the relevant population from which we attempt to draw inferences.

Table 10: Sample characteristics (Online survey 2016)

Variables	**Sample** (N = 836) Frequency (%)	**German average** [*] Frequency (%)
Gender		
Female	16.5	51.2
Male	83.5	48.8
Age		
18 - 24 years	3.3	9.8
25 - 29 years	2.8	7.3
30 - 39 years	9.3	14.3
40 - 49 years	18.2	20.1
50 - 64 years	46.7	24.6
65 years and older	19.7	24.0
Average monthly net household income (in Euro)		
less than 900	2.1	8.7
900 – 1.299	1.5	11.5
1.300 – 1.499	3.2	5.8
1.500 – 1.999	7.1	14.7
2.000 – 2.599	16.2	14.4
2.600 – 3.599	25.7	17.3
3.600 – 4.999	25.4	14.6
at least 5.000	18.8	13.1
do not know / not applicable	*n=119*	
Education		
No degree	0.4	9.8
Vocational School (9/10 years)	6.6	7.3
Secondary Modern School (10 years)	19.4	14.3
Grammar School (12/13 years)	18.8	20.1
University degree (university/university of applied sciences)	51.8	24.6
Other	3.1	24.0

[*] Percentages were provided by market research company *GfK* based on the census and the income and expenditure survey (Federal Statistical Office) in 2014.

Source: Own illustration

Responding to a willingness to purchase question, participants indicated high interest in battery storage systems.[19] Non-adopters were willing to purchase such a system when the price becomes reasonable (n=622; Mean: 3.94; SD: 1.2; 1 = strongly disagree, 5 = strongly agree). Almost 70% of the sample indicated willingness to purchase a system. To investigate consumer preferences in more depth, we now turn to the results of the choice experiment.

3.2.4.2. Estimation results

Table 11 shows the results of the mixed logit estimations. In our analysis, we define one reference level for each choice attribute to which the obtained utility values have to be compared to. As explained in Table 9, the reference levels are: residential storage system, use right, 25% autarky, external control, and specialized battery operator. The mean coefficients indicate the average utility for each of the choice levels. The presence of preference heterogeneity can be examined by analyzing the significance of standard deviations. Statistically significant levels reflect consumer heterogeneity—i.e. consumers value the specific level to varying degrees (Carlsson et al., 2003).

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[19] We adapted willingness-to-purchase from Wu et al. (2015): *"I will buy a residential battery system or participate in a community energy storage system as soon as the price is reasonable."*

Table 11: Mixed logit parameter estimates of the storage choice experiment

Variable	**Coef.**		**Std. Err.**
Mean Estimates			
None-option	-0.7684	***	0.0880
Cost (*Euro, NPV*)	-0.0002	***	0.0000
Community storage system	-0.0360		0.0476
Ownership	1.22535	***	0.0649
Payback period	-0.1671	***	0.0103
50% autarky	-0.0858		0.0562
75% autarky	0.2967	***	0.0574
100% autarky	0.8835	***	0.0573
Own control	0.1807	**	0.0527
Own control by default	0.2343	**	0.0683
External control by default	-0.2326	***	0.0470
Nationwide electricity supplier	-0.3496	***	0.0500
Regional electricity supplier	0.1730	**	0.0525
Regional energy cooperative	0.1611	**	0.0588
Standard deviation estimates			
Community storage system	0.6994	***	0.0385
Ownership	0.7904	***	0.0578
Payback period	0.1718	***	0.0089
50% autarky	0.2700	**	0.0943
75% autarky	0.5502	***	0.0822
100% autarky	0.8453	***	0.0586
Own control	0.0342		0.1166
Own control by default	0.2727	*	0.1065
External control by default	0.0322		0.0639
Nationwide electricity supplier	0.2437	**	0.0903
Regional electricity supplier	0.2283	*	0.0948
Regional energy cooperative	0.1616		0.1285

Notes: * $p<0.05$, **$p < 0.01$, ***$p < 0.001$.
Number of observations = 26752;
LR chi2(12) = 1 755.93; Log likelihood = -7207.74;
Prob > chi2 = 0.0000

Source: Own illustration

All parameter estimates are statistically significant except location (i.e., implementation concept) and autarky at the 50% level. The coefficient of the none option, i.e. the option to choose none of the presented storage systems, bears a negative sign, suggesting that respondents preferred choosing one of the presented systems over not choosing any system.

The parameter estimate of cost is highly significant at 0.1% with a negative coefficient. Storage systems with higher costs are less likely to be valued. Moreover, the estimate of the payback period is highly significant and shows a negative value. Consumers prefer cheaper systems and short payback periods. **H1a** and **H1b** are supported.

The estimate for the CBS storage concept is negative but not significant. Hence, the concept (either a residential or a community solution) has no noteworthy effect on respondents' choices. Findings do not support **H2**. Interpreting the significant estimate of the standard deviation, shows that the preferences for the two concepts are heterogeneous. We find differing tastes, some end-users value RBS and some CBS. This finding indicates support for both concepts even though RBS dominate the market. Moreover, due to limited knowledge about CBS and uncertainties, e.g. regarding their implementation, the results might even underline the potential for CBS.

The estimate for ownership of storage systems is highly significant and positive. Consumers prefer ownership over use rights. **H3** is supported. However, heterogeneous preferences show that some consumers prefer use rights. Although a high utility of ownership exists, some consumers prefer non-ownership modes. Ownership mode is an important business model component. Potential for use rights in Germany seems limited, although leasing looks promising for PV systems. Our findings align with Graebig et al. (2014) in suggesting ownership is likely to dominate preferences.

All estimates for autarky are highly significant compared to 25% autarky, except the parameter for 50% autarky, which shows null utility – perhaps indicating consumers prefer very high or modestly low levels of autarky. Utility values are positive for 75% and 100%, with 100% being highest utility. **H4** is supported, but only at sizable levels of autarky. Consumer heterogeneity prevails across all levels of autarky. Preferences for autarky drive adoption of storage systems. End-users desire autarky of 75% and higher. These findings extend recent research into autarky and self-sufficiency and confirm its importance.

Control settings on all levels are highly significant and affect preference patterns. *Own control* and *own control by default* show positive utility values. We find a negative estimate for *external control by default* compared to *full external control*. *Own control by default* offers the highest utility followed by *own control*. Hence, end-users prefer control but are willing to relinquish it during certain periods to provide grid services. However, *full external control* is preferred over *external control by default*, i.e. limited control for end-users. **H5** is supported. Preference heterogeneity exists for *"own control by default."* End-users want to control their systems but are willing to relinquish control to a partner and allow for grid services during certain periods. Preferences for the possibility to switch on the provision of grid services for certain periods over the possibility to switch it off (different defaults) exist. Consumers want assured control but prefer full automation over low levels of control.

Estimation results for partner companies are uniformly significant. The estimate for regional power provider is highest (i.e., is most preferred compared to a specialized battery operator). Utility for a regional energy cooperative is slightly less. The estimate for nationwide power providers is negative compared to a specialized battery operator. This finding suggests consumers prefer specialized battery operators over nationwide power providers. Well-established companies, namely nationwide and regional power providers, are not necessarily preferred over newer specialized operators or cooperatives. **H6** is not supported. Although we find stable preferences for cooperatives, preferences for nationwide power providers and regional utility companies vary. We find market opportunities particularly for regional providers and cooperatives to control and maintain storage systems, but also for third-party operators, automotive or battery manufacturers.

The willingness to pay results derived from our analysis are presented in Table 12. Respondents are willing to pay a premium of €7,690 in up-front investment to own a storage system compared to use rights. Willingness to pay is negative for payback period: to reduce it one year, consumers would be willing to pay €1,049 yearly. Respondents are willing to pay an additional €5,545 for full autarky, and €1,862 for 75% autarky compared to 25% autarky. We elicit price premiums for *own control by default* (€1,470) and *own control* (€1,134) compared to *full external control*. *External control by default* displays a negative willingness to pay (-€1,460). The acceptable price premium is €1,086 for regional power providers and €1,011 for regional cooperatives (reference level: specialized operator). Willingness to pay is negative (-€2,194) for nationwide utilities.

Table 12: Willingness to pay estimates for storage systems

	Willingness to pay (in Euro)
Ownership mode (Reference: use rights)	
Ownership	7,690.4
Payback period (per year)	-1,048.8
Autarky (Reference: 25% autarky)	
75% autarky	1,861.9
100% autarky	5,544.8
Control (Reference: External control)	
Own control	1,133.8
Own control by default	1,470.3
External control by default	-1,460.0
Partner Company (Reference: Specialized battery operator)	
Nationwide electricity supplier	-2,193.8
Regional electricity supplier	1,085.5
Regional energy cooperative	1,010.9

ns: not statistically significant

Source: Own illustration

3.2.4.3. Use rights and further usage of battery system

Following the choice experiment, we asked respondents what kind of use rights they were considering when making their choices (see Galassi & Madlener, 2014) and what assumptions they made about use of the system after 10-year use rights expired. Over one-third of respondents were thinking of leasing, rental, or tenancy (34%), followed by a sharing model (9%). One in 10 was thinking about another type of use rights. Nearly half had no type in mind (47%).

Most respondents (46%) assumed they could use the storage system without cost after the contract expired, 11% thought they could buy it by paying the residual value, and 9% thought they could continue paying a monthly fee. Some respondents expected to return the system to the partner company (5%) or stop using it (2%). A high share (27%) indicated no specific expectations.

3.2.5. Conclusion and policy implications

3.2.5.1. Conclusion

This paper contributes to a better understanding of consumer preferences for energy technology. Battery storage systems are an important element in a sustainable energy system with variable generation. The findings provide a basis to drive innovation in the field of energy storage. Based on our analysis, a high motivation to purchase storage systems awaits prices to fall. Innovative storage business models can increase the customer value and financial attractiveness of storage systems. Economic factors and preferences for high levels of autarky warrant emphasis as attributes for adopting battery storage. The anticipated decline in cost of lithium-ion batteries could satisfy desires for higher levels of autarky.

Our analysis shows that a market for residential and community storage concepts exists – opening opportunities for storage deployment on the household and community level. Collaborative business models for larger systems with joint use could increase autarky due to differences in power consumption patterns.

We find support for business models that use storage systems as a means to contribute to grid operation. This paper clarifies ambiguous results in previous studies and advances understanding of control and automation by taking a consumer perspective. Our results indicate end-users in Germany value control but are willing to relinquish it to support the grid if they can decide when. Models offering user-control with the option to activate grid services, and complete control by a trusted partner are promising. External control opens opportunities for connected residential or community systems with grid services that can be valuable for partner companies.

Opportunities exist for providers with regional ties and new entrants such as service providers. Third-party operators or battery and automotive manufacturers are acceptable partners and potential competitors for incumbents (see also Agnew & Dargusch, 2015). Energy cooperatives encourage customer involvement in the energy system, which could foster acceptance of storage systems (see Maruyama, Nishikido, & Iida, 2007). Storage technologies could provide a platform for both PV adopters and non-adopters. However, our results show that nationwide operators rather face consumer resistance.

The role of high levels of autarky has to be highlighted. Despite being a rather psychological issue in electricity markets, autarky is a key driver for battery storage adoption. We find a high willingness to pay for elevated levels of autarky. The predicted decrease in cost for lithium-ion batteries would also allow for achieving these higher levels of autarky.

Policymakers also confront the rise of PV and battery storage systems and potentially radical changes in the energy system (Agnew & Dargusch, 2015). The results presented in this paper may help forward-thinking public policy to promote diffusion of battery storage systems. For instance, policymakers could facilitate business models that support the grid.

3.2.5.2. Limitations and future research

Developing full business models for new storage concepts demands further analysis (e.g., taking into account fees and regulations). This study provides a foundation for future research and advances understanding of the customers value of battery storage systems, the core of a business model (Chesbrough & Rosenbloom, 2002).

Nevertheless, some limitations exist. First, preferences measured here are derived from a hypothetical choice experiment. A gap between stated and actual willingness to pay might exist. Second, a qualitative approach could analyze end-users' motives for control and provision of grid services in further detail. Third, better understanding of individual and collaborative investments is needed for instance with formal models spotlighting collaborative business models and new consumption modes that take a collaborative approach (e.g., community energy projects and shared usage). In this regard, new kinds of collaborations among different actors also need further investigation (see Römer et al., 2012; Verbong et al., 2016), as does the alignment of benefits for participants in collaborative business models (see Niesten & Alkemade, 2016).

3.2.5.3. Outlook

Financial and technical benefits foster the deployment of community systems, although barriers such as complexity of implementation exist, e.g. regulative issues and finding multiple users of CBS. High investment costs provide opportunities for business models involving partner companies and intermediaries. Collaborative business models could foster CBS and an orientation away from household-scale solutions to resource-sharing and collaborative energy solutions. This could also represent a step toward more sustainable production and consumption patterns. Furthermore, simultaneous use of end-user and grid applications can provide financial benefits for parties involved. Although extensive research examines new modes of consumption, we find support for ownership and limited potential for leasing or sharing. Wariness about new usage models might explain these findings. Information and trust-building could set the ground for non-ownership modes and product service systems.

3.3. Consumer preferences for electricity tariffs: Does proximity matter? *(ESSAY III)* [20]

Abstract

The introduction of renewable energy sources fosters the transformation from a centralized to a decentralized energy system. This alters the relation between consumers and power generation sites, as generation and consumption spatially converge. It allows for new configurations within the energy sector and provides opportunities for marketing regional energy. We empirically investigate consumer preferences for electricity generation in proximity to end users, focusing on the proximity of generation and providers, and present representative data for Germany. In a discrete choice experiment, a sample of 954 consumers chose from a range of different electricity tariffs. We estimate the willingness to pay for shares of regional generation, power providers, and electricity mixes. We find evidence in favor of regional production, but in spite of positive attitudes towards local generation from renewable sources, willingness to pay flattens out with higher shares of regional generation. In addition, a preference for regional providers exists. The results show that renewable energy mixes are preferred, particularly a solar and hydro

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[20] *Essay III* is based on Kalkbrenner, B. J., Yonezawa, K., & Roosen, J., 2017. Consumer preferences for electricity tariffs: Does proximity matter? *Energy Policy*, 107, 413–424. doi.org/10.1016/j.enpol.2017.04.009.

Bernhard Kalkbrenner designed the study, performed the analyses and wrote the paper. Koichi Yonezawa wrote an earlier version of the methods section and provided advice on the development of the paper and editorial input. Jutta Roosen provided advice on the development of the study, as well as editorial input, and participated in the data analysis.

mix. Thus, we find there is potential for business models offering regionally generated electricity.

Keywords: Discrete choice experiment, Decentralized energy, Electricity labelling, Local electricity supply, Renewable energy, Willingness to pay

3.3.1. Introduction

The energy system in Europe is characterized by a high degree of centralization (Naus et al., 2014). However, the current developments represent a transformation to a system with distributed generation (Jenkins & Pérez-Arriaga, 2017). Halu et al. (2016) see a shift from centralized large-scale electricity generation towards smaller generation sites at the local level. This small-scale generation is called decentralized energy or distributed generation (Pepermans et al., 2005). It can broadly be defined as *an electric power source connected directly to the distribution network or on the customer site of the meter* (Ackermann et al., 2001, p. 201; see also Theo, Lim, Ho, Hashim, & Lee, 2017). Decentralized electricity supply includes distributed generation such as solar systems and wind turbines, storage and controllable loads (Akorede et al., 2010; Peças Lopes et al., 2007). The importance of decentralized electricity supply is increasing (Koirala et al., 2016; Kubli & Ulli-Beer, 2016); e.g., due to cost and performance improvements of generation and storage technologies (Bharatkumar et al., 2013). Decentralized electricity supply–when based on renewable energies–can be a means to a secure and environmentally friendly future (Karger & Hennings, 2009). Quality and security of supply, affordability, and the potential for jobs and innovations at the local level have been attributed to decentralized energy (Halu et al., 2016; Koirala et al., 2016; M. O. Müller et al., 2011; Rae & Bradley, 2012). A decentralized system changes the relationship between citizens and power generation sites, since generation and consumption spatially converge (Koirala et al., 2016). It thereby shapes a new system with production in proximity to consumers and allows for regional production and consumption. Technological as well as societal developments can foster new ways of energy supply at the local and regional level, and open up opportunities for new tariff schemes marketing regionally generated electricity.

Until now, research on the energy system mainly focused on different types of technologies and ways of implementation, and neglected spatial aspects (Devine-Wright, 2011b). The analysis of decentralization is underreported in the literature (Kubli & Ulli-Beer, 2016), although citizens and communities need to support and accept a decentralized energy system for successful implementation (Wüstenhagen et al., 2007). The attitudes and preferences of citizens need to be incorporated in policymaking because citizens are directly affected by a decentralized electricity supply system. McKenna et al. (2015) state that consumers might prefer locally marketed electricity generation and call for further research to analyze these preferences. A current German initiative to regulate and introduce a labeling scheme for regionally generated electricity (BMWi, 2016a; EEG, 2016) stresses the relevance and need for analyzing local and regional energy concepts. Labeling and marketing regionally generated electricity from renewable sources as a specific product can help to foster the identification with local renewable energy sites and their acceptance, and support the further expansion of renewables (BMWi, 2016b). Furthermore, a label for regionally generated electricity from renewable sources could reduce information asymmetries and the uncertainty of consumers (Heinzle & Wüstenhagen, 2012). From a business perspective, regional generation could be an underrated selling point (Herbes & Ramme, 2014). Insights into consumer preferences are crucial for power providers in order to develop new business models and increase customer satisfaction (Amador, Gonzalez, & Ramos-Real, 2013).

The German market represents an interesting case for decentralization, since the electricity system is being developed from centralized generation to decentralized units of renewable energy production (J. Mattes et al., 2015). As part of the ongoing energy transition ("*Energiewende*"), Germany made the decision to shut down all nuclear power plants by 2022 (BMWi, 2014b). This *regime shift* (Strunz, 2014, p. 154) is characterized by a particularly high expansion of renewable energy sources and many small decentralized production sites (Karger & Hennings, 2009). Decentralized electricity is mainly generated from wind and solar power, as well as from biomass (Anaya & Pollitt, 2015). In 2015, renewable sources–in particular, wind and photovoltaics–generated 195.9 TWh of electricity. This represents 32.6% of the German gross electricity supply and an increase of 5.2 percentage points compared to the previous year (Umweltbundesamt, 2016).

We present new empirical evidence for consumer attitudes and preferences with regard to decentralized electricity supply by focusing on the spatial aspects of electricity generation and purchase. The objective of the present study is to examine if consumers show a preference for regional aspects when choosing an electricity tariff. We are interested in the willingness to pay for electricity that is produced close to the end users and focus on the proximity of generation and providers. Hence, proximity is defined as the proximity of electricity generation and the proximity of providers. This study, therefore, aims at investigating the spatial aspects connected with electricity tariff choice by analyzing (1) consumers' attitudes towards and preferences for electricity from renewable sources generated close to the end users, and (2) electricity tariff choice focusing on regional generation and the regional ties of the power providers. We test the following three hypotheses: H1, where consumers show a preference for electricity with a high level of regional generation; H2, where consumers show a preference for power providers that have regional ties; and H3, where consumers show a preference for electricity from renewable sources. The rationale of this research is based on a marketing perspective.

In our study, we examine empirical data from Germany. We use a choice experiment to investigate the spatial aspects of regional electricity generation and present the results of a survey conducted in Germany (N = 954) among residential energy customers who are in charge of energy-related and financial decisions, and the owners of renewable energy systems. We analyze the data from our experiment by using a mixed logit model and estimate the willingness to pay for the product attributes included in the analysis. This paper contributes to the advancement of research on decentralized electricity supply and provides valuable insights for power providers and policymaking at the national and regional levels.

The paper is organized as follows. In *Section 3.3.2*, we review the relevant literature. *Section 3.3.3* describes the data and gives an overview of the statistical model, followed by the empirical results and discussion in *Section 3.3.4*. The conclusions are presented in *Section 3.3.5*.

3.3.2. Literature review and hypotheses

3.3.2.1. Spatial aspects of a decentralized system

Socioeconomic research on energy asking the questions *what?* (technology and energy system), *how?* (type of project and their consequences) and *where?* (spatial aspects) have lacked a systematic focus on the last question of *where* energy is produced and consumed (Devine-Wright, 2011b, p. 58). In an energy system that is in the process of becoming decentralized, there is a need to understand the spatial aspects (Knapp & Ladenburg, 2015). Renewable energy generation brings about various impacts; e.g., on humans, the environment and the landscape, underlining the relevance of spatial aspects (Devine-Wright, 2011b; Pasqualetti, 2000). Proximity to generation sites has an influence on the attitudes of the public (van der Horst, 2007). The acceptance of regional energy projects depends on the type and size of projects and possibilities such as public participation (Hart, Stedman, & McComas, 2015; Pellizzone, Allansdottir, De Franco, Muttoni, & Manzella, 2015; Vecchiato & Tempesta, 2015). Concerns about local production; e.g., the visual impact of renewable energy sites (Sheikh et al., 2016), have been discussed and various papers have analyzed the social acceptance of renewable energies (e.g., Batel, Devine-Wright, & Tangeland, 2013;

Bronfman, Jiménez, Arévalo, & Cifuentes, 2012). Many of the studies on spatial aspects refer to the *not-in-my-backyard* (NIMBY) effect (Batel & Devine-Wright, 2015; Friedl & Reichl, 2016; Lienert et al., 2015). NIMBY is characterized by a positive attitude towards renewable energy sites in general, but a negative attitude or low acceptance if projects are located in direct proximity (Friedl & Reichl, 2016; Lienert et al., 2015). The concept has been subject to criticism (Burningham, 2000; Jones & Eiser, 2010; Swofford & Slattery, 2010; Wolsink & Devilee, 2009), since it represents *an easy to use and beguilingly simple way of thinking* (Devine-Wright, 2011a, p. 321). Such a simplified rule cannot explain local opposition (Wolsink, 2012b). In line with this, Batel and Devine-Wright see a *paradigmatic shift from NIMBY* (2015, p. 313). Recently, even preferences for local or regional energy generation have been found (Ebers & Wüstenhagen, 2016; Tabi, Hille, & Wüstenhagen, 2015). Still, the findings on energy generation in proximity to the end user are inconclusive (see Devine-Wright, 2013; Gamel, Menrad, & Decker, 2016; Hart et al., 2015; Wolsink, 2007; Wüstenhagen et al., 2007).

3.3.2.2. **Regionally generated electricity**

Marketing regionally generated electricity from renewable sources as a distinct product can help to foster the identification with local renewable energy sites and their acceptance, and support the further expansion of renewables (BMWi, 2016b). It requires labeling to make regional electricity identifiable. Furthermore, it could increase profits of the private operators of renewable energy sites, community energy projects and enterprises. Marketing regionally generated electricity had not been subject to regulation until recently German policymakers had completed the legislative process for introducing a labeling scheme (EEG, 2016). To our knowledge, no similar regulation on labeling exists in Europe. While a consistent definition and labeling might help to build trust, and avoid the uncertainty of consumers (Heinzle & Wüstenhagen, 2012), this issue is more complicated in the electricity market.[21] In the traditional connected grid, electricity generated within a region cannot be differentiated in a physical sense from other types of electricity. This situation can be different; e.g., for microgrids or for owners of a renewable energy system using electricity on site.[22]

Tabi et al. (2015) highlight the potential for marketing electricity generated within a region and recommend the introduction of standards for labeling the origin of electricity. A study of 136 providers of renewable energy in Germany found that nearly half of the companies expect an increasing demand for regional electricity products (Reichmutz, 2014). Almost 80% of the providers agree that regional aspects of energy generation and provision are important product attributes (Reichmutz, 2014). An analysis of the product strategies of power providers in Germany found that 27% referred to regional generation, but only 20% explicitly highlighted it. Hence, *made in the region* might be an underrated product attribute in the marketing practice of electricity tariffs (Herbes & Ramme, 2014).

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[21] Although many providers use labels to market their tariffs (Reichmutz, 2014), one has to keep in mind that only few consumers are aware of labels and certificates (A. Mattes, 2012).

[22] Microgrids are *small local distribution systems containing generation and load, whose operation could be totally separated (autonomous) from the main distribution system or connected to it (non-autonomous)* (Chicco & Mancarella, 2009, p. 543; see also Hatziargyriou, Asano, Iravani, & Marnay, 2007).

A new labeling scheme that allows one to market regionally generated electricity from renewable sources will enter into force in January 2017 in Germany as part of the 2017 Renewable Energy Sources Act (BMWi, 2016b; EEG, 2016). Such a label addresses *the desire of many market players to be able to market electricity generated from subsidized renewable energy which they supply to customers in the region as regional green electricity* (BMWi, 2016a). The Act defines regional electricity as electricity generated within a 50 kilometer radius of the postal code area of the final customer (EEG, 2016).[23] The larger the region, the more the energy sites that can be marketed as regional electricity. However, the smaller the radius, the higher is the connection of consumers and their identification with the sites. Hence, there has to be a balance between a narrow and broad definition. Besides the 50 kilometer definition, scholars have used a 20 kilometer radius (Braunholtz, 2003; Swofford & Slattery, 2010; Warren, Lumsden, O'Dowd, & Birnie, 2005) and a distance of 30 kilometers (Gamel et al., 2016; Sagebiel, Müller, & Rommel, 2014) to analyze the spatial aspects of energy systems.

3.3.2.3. Consumer preferences for electricity

Over the last few years, the market for renewable energy in Germany has been growing, with an increasing share–currently around 17% of households–purchasing a specific tariff that offers electricity only from renewable sources (Bundesnetzagentur/Bundeskartellamt,

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[23] A key aspect of regionally generated electricity is the definition of region size. Regions can be defined as either fixed; i.e., based on administrative districts, or flexible; i.e., based on the distance between the generation sites and households. The latter even allows including generation sites across national borders (BMWi, 2016b).

2014). Several scholars have studied consumer preferences for renewable energy by applying choice experiments, conjoint analyses or the contingent valuation method (Amador et al., 2013; Burkhalter et al., 2009; Goett, Hudson, & Train, 2000; Kaenzig et al., 2013; Lee & Heo, 2016; Litvine & Wüstenhagen, 2011).

Whether there is support or opposition for regional energy projects; e.g., generation sites, depends on the type of project and various factors like trust, justice and ownership (Hart et al., 2015; Tabi & Wüstenhagen, 2017; Wüstenhagen et al., 2007). However, marketing regionally generated electricity might be another means to achieve acceptance. While Rowlands et al. (2004) found that the location of generation is rather unimportant in Canada, Kaenzig et al. (2013) identified the location of energy production as one of the key product features for German consumers, besides the cost and electricity mix. Similarly, results for Switzerland show that electricity mix, cost and generation location are the most influential product attributes (Burkhalter et al., 2009). Electricity produced in the region or, at least, within national borders is preferred by consumers. A study by Tabi et al. (2014), which uses data from a choice experiment that was a subsample of the data by Kaenzig et al. (2013), analyzes different customer segments and underlines the relevance of the attributes of electricity mix, cost, and location of production. Generation location is a key product feature for *local patriots*, who are a customer segment that values regional and national generation almost as much as the price of electricity (Tabi et al., 2014, p. 210). Tabi et al. (2015) find that German consumers prefer renewable energy generated nationally. Moreover, a study in Switzerland finds that a willingness to pay for regionally generated electricity (within the canton) exists and that local consumers would, in the medium term, favor using locally generated electricity (Tabi & Wüstenhagen, 2015). Recently, Ebers and Wüstenhagen (2016) found support for generation from local sources in Switzerland. Almost 40% of the people would prefer generation at the local or regional levels. Therefore, regional generation could be a valuable feature for the differentiation of electricity tariffs (Tabi & Wüstenhagen, 2015). Vecchiato and Tempesta (2015) find a preference for small generation sites and mixed results on the preferences for regional generation. *Regional origin* is found to be an important product attribute and differentiator in other markets; e.g., in the food market (Hasselbach & Roosen, 2015). Hence, this phenomenon might also apply to renewable electricity generated within the region; e.g., as a means to support the local economy or provide a feeling of self-sufficiency and environmental benefits (Vecchiato & Tempesta, 2015). Drawing upon these findings, we hypothesize the following:

Hypothesis 1. Consumers show a preference for electricity with a high level of regional generation.

Various types of power providers from international companies to public utilities and locally-initiated cooperatives operate in the German market. Sagebiel et al. (2014) highlight that consumers value local providers. Rommel et al. (2016) find that consumers are willing to pay a price premium for electricity from renewable sources provided by municipally-owned energy companies and cooperatives. Consumers seem to show a higher willingness to pay for electricity provided by regional utilities and cooperatives that actively support the expansion of renewables (A. Mattes, 2012; Sagebiel et al., 2014). Sagebiel et al. (2014) show that regional ties; i.e., if the providers' headquarters are located within the region, have a positive impact on consumer choice.[24] An analysis by Goett et al. (2000) finds that customers value the local presence of power providers and that they would be willing to pay for it. Cooperatives can offer additional value to consumers due to their regional and local connection, transparency and democratic structure (Sagebiel et al., 2014). Hence, we propose the following hypothesis:

Hypothesis 2. Consumers show a preference for power providers that have regional ties.

In general, consumers are found to favor electricity from renewable sources (e.g., Mozumder et al., 2011). An increasing share of households is willing to purchase renewable energy and pay a price premium (Soon & Ahmad, 2015).[25] Soon and Ahmad (2015) find that the type of renewable source is unimportant on a global scale. However, in contrast, the sources of the electricity mix are a crucial feature for consumers in Germany (Kaenzig et al., 2013; Menges & Beyer, 2015). An analysis by Burkhalter et al. (2009) shows that the

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[24] In their analysis, providers were regarded as local if the distance between the providers' headquarters and customers was within a radius of 30 kilometers.

[25] Soon and Ahmand (2015) present a meta-analysis of willingness-to-pay studies focusing on 30 studies conducted in countries from all continents from 1996 to 2011. The mean willingness to pay for renewable energy equals a premium of US $7.16 per month compared to electricity from conventional sources. The authors argue that this finding is not an overestimation (Soon & Ahmad, 2015). A study in Italy finds an accepted premium of 22.2%; i.e., a mean monthly premium of 11.04€, for a tariff that provides electricity generated solely from solar (Vecchiato & Tempesta, 2015). Findings from the US and Japan show that consumers in both countries have a preference for electricity from renewable sources and are willing to pay *$0.71 and $0.31 per month for a 1% increase in the use of renewable source energy* (Murakami, Ida, Tanaka, & Friedman, 2015, p. 178). Recent studies present further details on preferences and willingness to pay (see Lee & Heo, 2016; Murakami et al., 2015; Vecchiato & Tempesta, 2015).

technologies used to generate electricity matter and that consumer preferences for specific renewable sources differ (see also Vecchiato & Tempesta, 2015). Kaenzig et al. (2013) state that consumers are willing to pay a premium for renewable energy, but significant variances exist in the amount of the relative premiums (see also Menges & Beyer, 2015). Sagebiel et al. (2014) and Mattes (2012) find a positive willingness to pay for electricity from renewable energy sources. In accordance with such findings, we propose the following hypothesis:

Hypothesis 3. Consumers show a preference for electricity from renewable sources.

3.3.3. Methodology

3.3.3.1. Methods

We use data from an online survey to investigate spatial aspects connected with regional energy generation. Following the framework by Devine-Wright (2011b), we focus on the spatial aspects, but also include the sources of generation in our analysis. First, the survey included measures on the importance of different product attributes of electricity tariffs (price, electricity mix, power provider and generation location) and a measure of attitude towards local generation of renewable electricity.[26] We used these direct measures to analyze the relevance of different product attributes and the attitude towards local generation of electricity. Second, a choice experiment on the

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[26] Measure: *"I would like to see electricity from renewable energy sources, so-called green energy, produced for local use in my municipality"*; measured on a 10-point Likert-type scale.

preferences for different electricity tariffs was conducted to test the hypotheses. Choice experiments are commonly used to measure the willingness to pay for different product features (Menges and Beyer, 2015). The choice experiment allows for decoupling of the product attributes, such as regional generation and providers with regional ties. Tabi et al. (2014), Kaenzig et al. (2013) and Burkhalter et al. (2009) use a similar approach to study consumer preferences. We connect with their findings and analyze more recent data.[27]

In our survey, respondents had to hypothetically choose a new electricity tariff. Each choice question implies a discrete choice between three electricity tariffs characterized by the attributes presented in Table 13. A sample choice task can be found in Appendix 4. We included four tariff attributes with four levels each in the experiment. Based on the hypothesis and previous research, we determined regional generation and the regional connection of the provider as the key aspects of our study. We also include electricity mix and price in our study, since they are found to be relevant product features (e.g., Kaenzig et al., 2013). We did not include a "none" option, since every consumer needs an energy tariff and not having a tariff would be unrealistic. Moreover, similar studies also excluded the "none" option (e.g., Kaenzig et al., 2013).

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[27] The mentioned studies analyze data collected in 2007 and 2009 – before the Fukushima nuclear disaster and the subsequent German energy transition (see Huenteler, Schmidt, & Kanie, 2012; Thomas, 2012).

Table 13: Attributes and levels used in the tariff choice experiment

Attributes	**Levels**			
Electricity mix	47% coal 17% nuclear 11% natural gas 9% wind 8% biomass 4% solar 4% water	47% coal 15% natural gas 15% wind 12% biomass 5% solar 6% water	50% wind 15% biomass 5% solar 30% water	15% solar 85% water
Electricity mix labels [b]	*German default mix 2013*	*Non-nuclear mix* [a]	*Renewable mix*	*Solar and hydro mix*
Monthly electricity cost per person in Euro	23,00€	28,00€	33,00€	40,00€
Percentage of locally produced electricity within a radius of 20 km	0%	33% [a]	66%	100%
Power provider	Foreign power provider	National power provider [a]	Regional power provider (e.g. municipally-owned utility)	Local energy cooperative

Note: [a] Reference level in data analysis; [b] Labels not shown in the choice scenarios

Source: Own illustration

First, the electricity mix attribute offers different generation source combinations. We included four different mixes: (I) the German default mix, including nuclear power, as well as non-renewable and renewable sources, based on the German mix from 2013 (AG Energiebilanzen, 2014); (II) a mix similar to the default mix, but without nuclear power (“non-nuclear”); (III) a mix based on wind, water, biomass and solar (“renewable mix“); and (IV) a mix of solar and hydro power (“sun and hydro”). In designing the tariffs, we took inspiration from Kaenzig et al. (2013). The tariffs represent the transition from nuclear and non-renewable sources to renewable sources, and comprise decentralized (solar, onshore wind, biomass) and centralized generation technologies (hydro, offshore wind, non-renewables, nuclear).

Second, we include electricity price in our experiment. The price levels in the choice experiment were determined based on the average costs of a three-person household in 2013 (bdew, 2013a).[28] We intended to use a similar, but less complex measure of willingness to pay than Kaenzig et al. (2013) by presenting monthly costs as the price per individual, not per household. With an average bill of 83.80€, the result is 28€ per person.[29] We used 28€ as a base level and included a price increase of approximately 20% and 40%, as well as a decrease of approximately 20%, as compared to the base level.[30] Hence, we defined the following monthly price levels: 23€, 28€, 33€, and 40€ per person.

Third, regional generation is a crucial element in our analysis. In order to market electricity as regional, the size of the region has to be defined and a specific share has to be generated within the region. Different radii have been used in research on the spatial aspects of the electricity system (e.g., Gamel et al., 2016; Sagebiel et al., 2014). The larger the radius, the more sites that can be included in the regional tariffs. The smaller the radius, the closer the sites are to the consumers and the higher the consumer identification with the sites (BMWi, 2016b). In our study, the generation facilities need to be located within

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[28] Average monthly electricity bill for a three-person household with a consumption of 3.500 kWh per year: 83.80€ (bdew, 2013a).

[29] In 2016, the average bill of a German household is 83.79€ per household; i.e., 27.93€ per person (bdew, 2016).

[30] According to Eurostat (as cited in Rommel et al., 2016), electricity prices in Germany between 2011 and 2013 varied between 0.25€ and 0.29€ per kWh, including taxes, representing a range of approximately 20%.

a radius of 20 kilometers (12.43 miles) of the consumers' homes to be classified as regional (see Swofford & Slattery, 2010). We decided in favor of a rather narrow radius in order to incorporate consumer identification with the sites and build a scenario in which consumers can imagine the impact of these generation facilities. In our survey, the levels of this attribute reflect the full range from zero to total regional production: 0% of the electricity purchased is produced within a radius of 20 kilometers, as well as 33%, 66% or 100% of the electricity purchased is produced in the region.

Finally, we included different power providers in order to take the relevant market players into account and, in particular, we considered the range of those providers with close regional ties to the end consumers and those without (Kaenzig et al., 2013; A. Mattes, 2012; Rommel et al., 2016). Regional generation can be characterized by the distance between the providers' headquarters and the customers (Sagebiel et al., 2014), or having a regional presence (Goett et al., 2000). We included foreign power providers, German nationwide power providers, regional power providers (e.g., municipally-owned utilities) and locally based energy cooperatives in our analysis.[31] More than 970 cooperatives with local and regional ties operating in Germany are an essential force in the decentralized energy system (Kalkbrenner & Roosen, 2016; Kubli & Ulli-Beer, 2016; J. R. Müller & Holstenkamp, 2015). To contrast and compare national, regional and local providers, we also included foreign operators.

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[31] Out of the 1100 power providers operating in Germany, households can, on average, choose between 91 providers in their network area (Bundesnetzagentur/Bundeskartellamt, 2015).

We created an 'optimal orthogonal in the difference' design (OOD) using *Ngene* software (Street, Burgess, & Louviere, 2005). The full factorial of this design is composed of 256 possible combinations. We limited the number of choice sets to reduce the cognitive effort required and prevent fatigue effects (Meas, Hu, Batte, Woods, & Ernst, 2014; Swait & Adamowicz, 2001). Hence, we used a fractional factorial design that resulted in 28 choice sets. The resulting MNL d-error was 0.0327. We blocked the sets into seven equal-sized blocks. Each respondent was allocated one block with four choice tasks. Hence, each respondent received a series of four choice tasks– comparing three tariffs with different attribute levels and choosing one out of the three tariffs. To reduce potential hypothetical bias and increase the validity of our measure, we included a detailed description of the scenario and used an adjusted version of a cheap talk script by Lusk (2003), Shogren et al. (2000) and Cummings and Taylor (1999). This also helped to remind respondents of their budget constraints.

3.3.3.2. Data collection

The data were collected by means of an online questionnaire from July until August, 2014. A marketing research company *(GfK)* recruited the respondents and conducted the survey. The target population of the study consisted of citizens who are in charge of energy-related and financial decisions in their respective households and owners of renewable energy systems. A total of 1021 respondents completed the online questionnaire. We excluded respondents from further analysis based on completing the survey in under 14.7 minutes (1.0 SD below the sample mean). The final sample consisted of 954 participants, including 780 household decision-makers, of which 30 are shareholders in a renewable energy system, and 174 owners of a renewable energy system, of which 21 also own shares. The owners have at least one of the following types of systems in place: PV system (120 respondents), solar thermal unit (85 respondents), heat pump (27 respondents), wind turbine (9 respondents), block-type thermal power station (5 respondents) and biomass power plant (4 respondents). Forty-three respondents are members of a renewable energy initiative; e.g., a cooperative. The sample of household decision-makers was drawn by quota sampling and is representative as regards to age, education, employment status and income. Table 14 summarizes the characteristics of the respondents. Overall, the total sample provides a wide variation in age and income. Male respondents are slightly overrepresented in comparison to the general population. Nevertheless, the sample is relatively close to the characteristics of the German population and suitable for generating reliable estimates.

Table 14: Selected sample characteristics (Online survey 2014)

Variables	**Sample** (N = 954)	**German average** [a]
	Frequency (%)	Frequency (%)
Gender		
Female	45.6	51.2
Male	54.4	48.8
Age		
18 - 24 years	8.9	9.8
25 - 29 years	6.8	7.3
30 - 39 years	15.0	14.3
40 - 49 years	20.4	20.1
50 - 64 years	30.9	24.6
65 years and older	17.9	24.0
Average monthly net household income (in EURO)		
less than 900	6.9	8.7
900 – 1.299	8.4	11.5
1.300 – 1.499	6.4	5.8
1.500 – 1.999	15.8	14.7
2.000 – 2.599	16.4	14.4
2.600 – 3.599	22.3	17.3
3.600 – 4.999	15.8	14.6
at least 5.000	8.2	13.1
do not know / not applicable	*n=154*	

Note: [a] Percentages were provided by the market research company *GfK* based on the census and the income and expenditure survey (Federal Statistical Office).

Source: Own illustration

3.3.3.3. Statistical model and data analysis

To analyze the data from our experiment, we use the random utility framework (McFadden, 1974). Specifically, the utility of individual i from choosing tariff j at time t is written as a linear function of tariff attributes and a random error. That is:

$$U_{ijt} = \beta^0 PRICE_{ijt} + \sum_{k=1}^{K} \beta_i^k X_{ijt}^k + \epsilon_{ijt}, \qquad (1)$$

$$\beta_i^k = \bar{\beta}^k + \theta_i^k, \theta_i^k \sim N\left(0, {\sigma^k}^2\right), \qquad (2)$$

where β^0 and β_i^k $(k = 1 \cdots K)$ are the parameters to be estimated, $PRICE_{ijt}$ is the price, X_{ijt}^k is the kth non-price attribute of tariff j at time t and ϵ_{ijt} is the random error component. All coefficients–except the one for price–are specified as random following a normal distribution. We specify the price coefficient to be fixed (Hole & Kolstad, 2012). For our estimation, we assume ϵ_{ijt} follows an independent and identically distributed extreme value type 1, so the probability that individual i chooses tariff j at time t is given by:

$$P_{ijt} = \int \cdots \int \frac{\exp(\beta_i^0 PRICE_{ijt} + \sum_{k=1}^{K} \beta_i^k X_{ijt}^k)}{\sum_{j=1}^{J} \exp(\beta_i^0 PRICE_{ijt} + \sum_{k=1}^{K} \beta_i^k X_{ijt}^k)} dF(\theta_i^1) \cdots dF(\theta_i^K), \qquad (3)$$

where $F(\cdot)$ is the cumulative standard normal distribution and θ_i^k are normally distributed terms designed to account for any unobserved heterogeneity in the marginal utility. Notice that we assume zero correlation among θ_i^k. We estimate equation (3) using the simulated maximum likelihood method (Train, 2009). This method provides consistent parameter estimates under rather weak regularity conditions. To calculate the willingness to pay, we assume that the price coefficient does not differ between consumers:

$$WTP = -\frac{\beta_i^k}{\beta^0} \qquad (4)$$

We use *Stata's mixlogit* and *wtp* commands to estimate our model (Hole, 2007). In order to increase the computational speed and efficiency of the estimation, we use 500 Halton draws for realizations of each of θ_i^k (Bhat, 2003; Hole, 2007).

3.3.4. Results and discussion

3.3.4.1. Descriptive results

We asked respondents which product attributes influenced their choice of electricity tariff. Table 15 shows the average importance of the product attributes in terms of generation location, provider, electricity mix and price measured on a five-point Likert scale. We also offered respondents a “not applicable/don’t know” option. The results show that the price of electricity is the most important attribute. Electricity mix and power provider are also important decision criteria. Participants reported a slightly lower importance for the location of generation. This indicates that the location of energy production seems to be a less important than the other product criteria. However, the standard deviation is slightly higher for location than for the other attributes, indicating a wider spread of the observations.

Table 15: Relevance of the attributes of electricity tariffs (ordered by mean)

Product attribute	**Mean**	**Std. deviation**
Price	4.53	0.779
Electricity mix	3.49	1.266
Type of power provider	3.44	1.273
Generation location	3.09	1.314

Measure: *Imagine you have to choose a new electricity tariff. How would the following product criteria influence your choice of a new electricity tariff? (1=not important at all; 5 = very important);*

Source: Own illustration

Furthermore, we measured the preference for the local generation of renewable energy as one’s attitude towards local generation. On average, the attitude towards local generation of electricity from renewable sources within the municipality was positive (Mean: 7.53; SD: 2.41; 1 = low preference, 10 = high preference). These measures act as indicators of preferences. However, they can be confounded by other factors. In order to verify our findings, we turn to the results of the choice experiment.

3.3.4.2. Parameter estimation results

In the stated choice experiment, we analyze the impact and relevance of the share of regional generation and the regional ties of power providers in detail. For each product attribute (electricity mix, regional generation, and power provider), we define one level as the reference level. We use the non-nuclear mix, 33% regional generation and national provider as our reference levels. We applied effects coding to the choice data for electricity mix, local generation, and power provider. Price is coded as a continuous variable. First, we estimated a multinomial logit model and performed the Hausman procedure to test the independence of irrelevant alternatives (IIA) assumption (Hausman & McFadden, 1984). The results show that the IIA assumption does not hold. Therefore, the data are modeled in a mixed logit model, also called random-parameters logit (McFadden & Train, 2000; Revelt & Train, 1998). Mixed logit models allow one to capture unobserved heterogeneity and have been used frequently (Colombo, Hanley, & Louviere, 2009).

Table 16 presents the results of the mixed logit estimations. The coefficients represent the utility attributed to each level in the choice experiment. The standard deviations reflect the heterogeneity of preferences. Statistically significant standard deviations show that consumers value certain aspects to varying degrees (Carlsson, Frykblom, & Liljenstolpe, 2003).

Table 16: Mixed logit parameter estimates of the tariff choice experiment

Variable	**Coef.**	**Std. Err.**
Mean Estimates		
Price	-0.1315***	0.0049
100% regional production	0.0598	0.0501
66% regional production	0.0473	0.0424
0% regional production	-0.1178**	0.0434
Local cooperative	0.2041***	0.0430
Regional provider	0.4711***	0.0457
Foreign provider	-0.7886***	0.0555
Solar and hydro mix	0.5047***	0.0443
Renewable mix	0.4071***	0.0455
German default mix	-0.5109***	0.0560
Standard deviation estimates		
100% regional production	-0.0222	0.1242
66% regional production	0.0166	0.1522
0% regional production	0.0460	0.1882
Local cooperative	0.0192	0.1524
Regional provider	0.3765***	0.0740
Foreign provider	0.4325***	0.0806
Solar and hydro mix	0.3818***	0.0813
Renewable mix	0.4902***	0.0667
German default mix	0.4332***	0.0940

Notes: **p < 0.01, ***p < 0.001.
Number of observations = 11448;
LR chi2(9) = 67.69; Log likelihood = -3168.3521;
Prob > chi2 = 0.0000

Source: Own illustration

Price. The parameter estimate of price is highly significant at the 0.1% level. As expected, the coefficient of price is negative, suggesting that lower prices are preferred. The cost of electricity is a significant parameter of energy tariff choice. Consumers prefer lower bills over higher ones.

Regional generation. As regards regional generation, only the parameter estimate of 0% regionally generated electricity is found to be statistically significant. Its coefficient is negative, indicating that consumers show a negative preference for no regional generation as compared to a level of 33% regional generation. The levels of 66% and 100% regional generation show positive coefficients, but they had no significant effect on the respondents' choices. The preference for electricity that is generated regionally, within a radius of 20 kilometers, as stated in **H1**, is partially confirmed. Tariffs offering 33% regional generation are preferred to those with no regional generation. Although we find positive utility values for high shares of regional generation, preferences do not significantly increase for tariffs with shares above 33% regional generation. Scope insensitivity might be a reason (see Olsen, Donaldson, & Pereira, 2004). Consumers value a share of regional generation, but do not sensitively react to the specific share of regional generation. These findings connect to research that finds a willingness to pay for regional generation (e.g., Tabi and Wüstenhagen, 2015).

Power provider. We find significant results for the type of provider. Coefficients for both regional providers, such as municipally-owned utilities, and local energy cooperatives are positive. Hence, they are preferred over national providers. Consumers show a negative preference for foreign providers as compared to German national providers. We, therefore, find support for **H2**. The type of provider, its geographic proximity and regional ties are found to be important product attributes. While we see preferences for providers located and operating in the region; i.e., regional public utilities and local energy cooperatives, we find a negative utility value for foreign providers. The preferences for energy cooperatives are homogeneous, while respondents show heterogeneous preferences in regard to regional and foreign providers. This is in line with Rommel et al. (2016), who find heterogeneous preferences for the type of provider. To sum up, the regional ties of providers seem to be a crucial determinant. One could see a continuum of preferences ranging from providers with regional ties to those with national or international ties.

Electricity Mix. Parameter estimates of electricity mixes are highly significant at the 0.1% level. The coefficients for both electricity mixes offering renewable energies (solar and hydro mix, renewable mix) are positive, indicating that customers generally prefer renewables. The tariff offering an electricity mix from solar and hydro power is most preferred. A tariff providing electricity from a mix of renewables (solar, hydro, wind, and biomass) also carries a higher utility value compared to a non-nuclear mix (coal, natural gas, and renewable energies). The coefficient for the German default mix–electricity from nuclear, non-renewable, and renewable sources–is negative. This suggests that consumers have a negative preference for the default mix as compared to a non-nuclear mix. Hence, our findings provide support for **H3**. We find heterogeneous preferences in regard to the electricity mixes; i.e., some consumers value the electricity mixes, while others do not. In line with similar research, the electricity mix shows a strong influence on customer choices (e.g., Kaenzig et al., 2013).

Table 17 shows the willingness-to-pay estimates. The parameters display the same significances as in the mixed logit model. Hence, all estimates are significant, except the parameter estimates for regional generation at the 66% and 100% levels. Overall, our analysis is based on an average monthly cost of electricity of 28€ per person (BDEW, 2013). Respondents are willing to pay 0.90€ less for a tariff with 0% regional generation as compared to a 33% share of regional generation. The price premiums for 66% and 100% shares of regional generation are not found to be statistically significant. We elicit a price premium of 3.58€ for regional utilities; e.g., municipally-owned providers, and 1.55€ for energy cooperatives, as compared to national providers. A negative willingness to pay (-6.00€) was found for foreign providers as compared to national providers. The additional mean willingness to pay for a solar and hydro tariff is 3.84€ per month, and 3.10€ for a renewable power mix (including solar, hydro, wind, and biomass) as compared to a non-nuclear mix. We find a lower willingness to pay for the German default mix than for a non-nuclear mix (-3.89€).

Table 17: Willingness to pay estimates for tariffs

	Willingness to pay (in Euro per month)
Regional generation (Reference: 33% regional generation)	
100%	0.46 (ns)
66%	0.36 (ns)
0%	-0.90
Provider (Reference: National provider)	
Local cooperative	1.55
Regional provider	3.58
Foreign provider	-6.00
Electricity mix (Reference: Non-nuclear mix)	
Solar and hydro mix	3.84
Renewable mix	3.10
German default mix	-3.89

Notes: ns: not statistically significant at the 5% level

Source: Own illustration

Consumers have the highest willingness to pay for tariffs that offer electricity from solar and hydro power (13.7% price premium on the average bill of 28€ per person) and for tariffs offered by regional providers (12.8% price premium), followed by a renewable energy mix based on solar, hydro, wind and biomass (11.1% price premium). The willingness to pay for electricity offered by locally based energy cooperatives equals a premium of 5.5%. We find negative willingness-to-pay estimates for the following attributes: no regional generation (-3.2%) as compared to a level of 33% regional generation; a mix based on nuclear, non-renewable, and renewable sources (-13.9%) as compared to a non-nuclear mix; and tariffs from foreign providers (-21.4%) as compared to national providers.

3.3.5. Conclusion and policy implications

Decentralization of the electricity system opens up new opportunities for consumers to relate to energy supply. This study centered on the spatial aspects of an electricity supply system that is in the process of becoming decentralized. The decentralization of the electricity supply and the expansion of renewable energies change the relationship of citizens and the energy system, since citizens are more directly affected by the generation sites. We investigated the preferences for regionally generated electricity and the regional ties of power providers in Germany. Insights on consumer preferences and willingness to pay are crucial for power providers when determining new tariffs, but they can also help policymakers (see Amador et al., 2013). We analyzed data from a 2014 survey of 954 respondents conducted in Germany and identified key factors of electricity tariffs with regard to a decentralized electricity supply. The typical respondent prefers lower prices over higher prices. We find that the electricity mix, type of provider and proximity play a role in tariff choice. Consumers' attitudes towards regionally generated electricity from renewable sources are positive and preferences exist for this type of electricity. We find that, although price and electricity mix are crucial, regional aspects can, in fact, be relevant determinants for electricity tariff choice. Consumers show a preference for electricity from renewable sources, in particular a sun and hydro mix, and for power providers that have regional ties. Preferences exist for regionally generated electricity; however, in spite of positive attitudes towards local generation, there is no additional willingness to pay for regional generation shares above 33%. The findings indicate support for renewable energies, regardless of whether they are decentralized or centralized generation technologies. Due to the design of our study, we cannot disentangle the particular effects of centralized or decentralized generation on consumer preferences.

Our work helps to better understand and explain the value of proximity by analyzing the impact of the extent of regional generation, the energy mix, and the regional connection of power providers. Our study extends previous work on the willingness to pay for electricity. It explores consumer preferences for electricity from renewable sources generated close to the end users and highlights the relevance of regional aspects regarding energy supply. We, thereby, contribute to a better understanding of the transition towards a decentralized electricity supply based on renewable energies. The findings help to clarify the preferences for and against electricity generated in proximity to end users, and underline the *where*, besides the *what* and *how* in the social science energy framework of Devine-Wright (2011b).

The findings support the decentralization of the electricity supply, while they also show the limits from a consumer perspective. Overall, we find that consumers are willing to pay a price premium for electricity. Positive attitudes exist for local generation from renewables in the community. Citizens favor some generation facilities located in the region or community, but as long as there is some regional generation the specific share seems to be negligible and the accepted price premiums are limited. These findings add to the literature on spatial aspects of the electricity system. Our study confirms the findings by Batel and Devine-Wright (2015), Devine-Wright (2011a) and Wolsink (2012b), thus showing the limited usefulness of the

NIMBY concept. We find a positive attitude towards local renewable energy projects and preferences for a share of regional generation.

Most of the renewable energy marketed in Germany is not generated nationally, but in, for example, Norway or Austria (Herbes & Ramme, 2014; Mulder & Zomer, 2016). Our findings show that there is potential for electricity from renewable sources that is produced *in the region*. Utilities could promote regional generation and develop new types of electricity tariffs. Our study supports the findings by Herbes and Ramme (2014) that local generation might be underrated by power providers. The results present empirical support for regional electricity tariffs and concepts, such as the labeling that will be in force in Germany in 2017 (EEG, 2016). Marketing regionally generated electricity can support the decentralization and acceptance of renewable energy sites located close to consumers (BMWi, 2016b). Regional energy can be a means to engage citizens with the energy system. We used a 20 kilometer radius to define regional generation in order to attain a high identification of the respondents with the generation sites. However, a larger radius, such as that in the German regulations, might be more feasible from a company perspective. When designing regional tariffs that provide renewable energy, it is valuable for energy companies to communicate their electricity mix, company type and regional ties, as well as regional generation, with consumers. Future labeling schemes could state the specific share of energy generated regionally. However, at present, such information appears not to be valued by consumers. The scope insensitivity can facilitate regional tariffs from a business perspective, since a low–or even undefined–share could be generated regionally. This, however, might lead to ambiguity for consumers and may require regulatory oversight.

Our results provide support for the role of providers with regional ties. Regional utilities or cooperatives are in a favorable position to market regionally generated electricity. Since the kind of provider is found to be crucial, energy suppliers such as cooperatives should communicate and highlight their firm type and regional ties. The preference for regional power providers over cooperatives is in line with similar research that finds a slightly higher willingness to pay for regional providers (municipally-owned) than for cooperatives in Germany (Rommel et al., 2016). The high market share of regional providers, almost 53% of household customers (Apergis, 2014), and a high level of trust in municipally-owned regional companies (VKU, 2016) could explain this preference.

This study centered on regional electricity supply in a decentralized system with a rather narrow view. Looking ahead, with an expansion of the decentralized power supply, the distribution system is being transformed from a one-directional to a *bidirectional network* (Khalilpour & Vassallo, 2015, p. 220; Passey et al., 2011). The role of individuals and households on the customer side of the meter transforms from passive consumers to *active participants* in the system (Schot et al., 2016, p. 6). These developments foster decentralization and change the ownership structure of generation sites, since an increasing number of sites is owned by individuals and community energy projects.[32] With a rising share of households engaging in the energy system, new concepts develop such as peer-to-peer business models and microgrid infrastructures can be implemented. Creating such infrastructures can also alter the traditional grid system (Parag & Sovacool, 2016) and put pressure on the tariff system and incumbents in the overall electricity market. As the dependence of the owners of renewable energy systems and members of microgrids shrinks (see Wolsink, 2012a), prices for households not generating electricity are likely to increase due to the *socialization of connection costs* (Anaya & Pollitt, 2015, p. 484). Moreover, high shares of decentralized generation can put the distribution network under pressure, resulting, for instance, in voltage problems (Anaya & Pollitt, 2015; Pollitt & Anaya, 2015). Hence, there is a need for businesses and policymakers to recognize decentralization. Although radical changes can be observed in the electricity system, the business models and tariffs do not reflect these developments; e.g., in the German market.

There are a number of limitations associated with our study that provides avenues for future research. In the choice experiment, interaction effects; e.g., between regional generation and type of energy source, might exist (see also Rommel et al., 2016) that we cannot account for due to the design of the choice experiment. Further research could focus on these interactions. The calculated willingness-to-pay estimates are in the range of similar studies (marginally lower) which could be an indicator of reliable findings (see Kaenzig et al.,

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[32] Households and community initiatives own approximately 47% of the total installed capacity of renewable energies in Germany (trend:research/Leuphana Universität Lüneburg, 2013).

2013; Soon & Ahmad, 2015). These measures present the preferences in a straightforward way, but they have to be interpreted with care. Since our experiment was hypothetical, the estimates should be interpreted as the upper bound of the willingness to pay (Goett et al., 2000). Furthermore, we have to acknowledge the gap between the hypothetical and actual willingness to pay, and the limitation that a positive willingness to pay will not directly lead to switching the provider or tariff–as seen in the rather low switching rates in Germany (McKenna et al., 2015; Menges & Beyer, 2015).[33] Studying the attitude-behavior gap and how to achieve a real switch may provide new and valuable insights. As mentioned by Kaenzig et al. (2013), our results reflect the preferences of an average consumer. Particular segments might have specific preferences and willingness to pay. A key aspect for regional electricity labeling is the definition of the region, as a fixed (based on administrative districts) or a flexible concept (based on the distance between the generation sites and households). Future research could investigate regional labeling in further detail; e.g., by examining different radii such as the 50 kilometer distance used in the 2017 Renewable Energy Sources Act (BMWi, 2016a; EEG, 2016). Finally, we need further research on energy certification and labeling from a consumer perspective, since even the present regulations in Germany are complex. Although labels can be useful for consumers, they should be easy to understand and transparent to help consumers make informed decisions (see Heinzle & Wüstenhagen, 2012). Investigating the extent consumers understand the present electricity

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[33] In recent years, the switching rate in Germany has been increasing: 5.6% of households switched their power provider in 2014 (Bundesnetzagentur/Bundeskartellamt, 2015).

labeling system can function as a starting point for further analyses (see Bettinger & Holstenkamp, 2015; Conrads, Meyer, & Litzenburger, 2016; Maaß & Praetorius, 2015).

Our empirical analysis supports regional energy concepts based on renewable sources. Consumers are willing to pay higher prices for providers with regional ties and (with limitations) for regional generation. Hence, they are willing to support the transformation towards a decentralized electricity supply with generation from renewable sources at the local and regional levels.

4. Conclusion

4.1. Main findings and discussion

The decreasing prices of sustainable energy technologies such as PV systems, battery storage systems and wind turbines are facilitating their proliferation. Expanding generation from renewable energies promotes a more decentralized energy system. In addition, the digitization and increasing electricity energy costs could drive this transformation. These developments are further supported by new ways of participating and investing in the energy supply – already an important part of the German energy system today (J. Mattes et al., 2015). Changing towards a more decentralized and potentially more sustainable electricity system requires not only technological innovation but also individual contributions. The decentralization with energy generation, storage and grid infrastructure in proximity to end-users changes the relationship between households and the energy system by allowing for new kinds of engagement and by making energy more visible. There are various opportunities on the individual or community level for citizens and households to actively engage, on a participatory continuum ranging from traditional consumer roles to producer roles, and from non-monetary engagement to minor and major investments. Consumers in the future energy system are therefore likely to have a more important role than they currently do.

This dissertation has studied consumers' attitudes, preferences and intentions in a changing energy system. It examined selected topics on a rather decentralized electricity system from a consumer research perspective. The overall research aim was to analyze the roles of consumers and the different ways for households to engage in the changing electricity system in Germany. The study, particularly, addressed the following research question: *What are consumers' attitudes and preferences regarding participation and selected energy-related behaviors in an energy system that is in the process of becoming more decentralized?* The research centered on Germany, since it is currently widely transforming its energy system. Based on a market logic and a participation logic, the dissertation investigated consumers' attitudes and preferences regarding community energy, battery storage systems and electricity tariff choice to contribute a better understanding of the new consumer roles and of the new ways to take part in the electricity system. The research aimed to advance knowledge on consumer behavior and pro-environmental behavior to facilitate the transition towards a renewable energy system. The dissertation improves the understanding of new modes of generation, i.e. community energy, the adoption of battery storage systems, and the potential of marketing regionally generated electricity. The findings from these studies were presented in full in the three essays.

The first essay presented an analysis of consumer participation in local renewable energy projects. It investigated the potential for implementing community energy projects – focusing on how community identity, social norms and trust have an effect on the willingness to invest and volunteer in local renewable energy projects.

Energy generation from renewable sources at the local and regional levels is accepted by large parts of the population. The study showed a high willingness to participate in community-based energy projects with the objective of local generation, storage and usage of electricity. The results indicate that citizens are more willing to volunteer than to invest financially in local renewable energy projects. Potential contributors to community energy projects are more likely to have a higher income, be male, live in a rather rural or sub-urban area, and have a renewable energy system in place, such as a PV system. The analysis highlights the role of social motives, i.e. social norms and trust, in addition to pro-environmental motivations for participating in renewable energy projects. Trust and social norms are important drivers of community energy engagement. Community identity represents a weaker predictor of participation.

These findings advance the understanding of community energy schemes and pro-environmental behavior. Moreover, they contribute to research on community-based solutions and how to actively engage consumers in the energy system. The essay finds that opportunities for community energy solutions exist. The role of peers, community and trust should not be ignored in community-based initiatives. Taking social aspects like trust, social norms and community identity into account can be of value for existing community energy projects, as well as for starting such projects. It can, furthermore, be useful for setting appropriate incentives. The high willingness to participate – higher for volunteering than for investing financial resources – provides overall support for further community energy projects and grass-roots initiatives.

The second essay contributes to a better understanding of consumers as investors in and co-owners of battery energy storage technologies by empirically investigating the preferences for such systems. There is high interest in purchasing a battery storage system among potential adopters, provided the price be reasonable. The findings indicate potential for both residential systems and larger community concepts. Furthermore, the results show that low costs and high autarky levels are crucial for battery storage adoption. There is limited potential for new ownership models, such as leasing or sharing, in the present market. Storage systems can provide grid services, and consumers are willing to relinquish some control to activate such services, although they prefer having the control. Hereby, varying preferences for different default settings were found. Regional utility companies and cooperatives are the preferred partners for the control and maintenance of storage systems. Besides, opportunities in the storage market were found for intermediaries, battery and automotive companies.

The study highlights the future potential and role of energy storage and presents key product attributes for battery systems, i.e. price, autarky, and ownership mode, which can be valuable for developing business models. Price seems to be a main factor for adoption. The expected decrease in battery system costs is likely to facilitate the further adoption of storage systems, which will reinforce the transformation of the energy system towards being a bi-directional network. The importance of autarky reflects a preference for having control over energy generation, storage and usage – making energy *your own*. In particular, the concept of community battery storage systems could offer technical and economic benefits over residential systems due to operational advantages and economies of scale. Opportunities in the energy storage market might open up not only for regional providers and cooperatives, but also new market entrants. The study contributes to research on sustainable technology adoption and business models in the energy sector, and to the economic literature on battery storage systems. Furthermore, it advances the understanding of joint usage and resource sharing, showing routes for community-scale deployment. Renewable energies could be further integrated by a combination of different storage system applications and an increasing number of these being used to provide grid services. New business models that motivate end-users to relinquish control could facilitate the provision of grid services on a larger scale, supporting the integration of renewable energies and driving the energy transition in Germany.

The third essay explores consumers' electricity tariff choices. A rather decentralized energy system with distributed sites makes it possible to generate and market electricity produced in proximity to the end-user. The study investigated consumer preferences for regionally generated electricity. Key product attributes include not only price and electricity mix, but also the type of power provider. The empirical analysis shows a high acceptance of energy generation from renewable sources in proximity to the end-user. Findings show that consumers state a preference for renewable energies, in particular for a mix of solar and hydro power, and for providers with regional ties. More precisely, regional utility companies and locally based energy cooperatives are the preferred providers. A tariff offering regionally generated electricity is favored over no regional generation, but consumers do not sensitively react to shares above 33% of regional generation. Willingness to pay flattens out with higher shares of regional generation. The findings on the spatial aspects of the energy system show the potential for a decentralized energy system with local and regional generation and marketing of electricity. The paper presents key attributes for electricity tariffs.

These findings are particularly relevant in light of the regional electricity labeling that will enter into force in Germany in January 2017, as part of the 2017 Renewable Energies Act (EEG, 2016). They show opportunities for tariffs providing regionally generated electricity at the local and regional level. Regional energy concepts could become relevant cornerstones of a more decentralized energy system, increasing the acceptance of regional generation sites and supporting the further energy transition in Germany (see BMWi, 2016b). As the results of this essay contribute to a better understanding of the socio-economic aspects of a decentralized energy system, they are not only relevant for power providers, but also for policy-makers – providing a basis for regional energy concepts and labeling schemes. If the stated preferences for renewable energy generated regionally and provided by energy companies with regional ties translate into actual behavior (tariff choice), the decentralization with generation and consumption on the local and regional level could be supported. This would, in turn, provide opportunities for community-based organizations and regional providers, and establish a new relation between consumers and energy supply. In this way, marketing of regional energy could facilitate market acceptance and consumer participation. The findings contribute to research by reframing the rather negative perception of local and regional energy generation facilities – often referred to as the NIMBY phenomenon – to a more positive perspective. In line with Wolsink (2012b) and Devine-Wright (2011a), this dissertation illustrates the limited usefulness of the NIMBY concept, since it is over-simplifying a complex topic.

Overall, this dissertation has analyzed the role of households in the changing German energy system. The studies presented valuable findings on local and regional electricity generation and storage, as well as on electricity tariffs with specific insights into how consumers participate in an energy system in the process of becoming more decentralized. As the share of decentralized energy generation from renewable sources increases, generation and consumption are spatially converging. This fundamentally alters the relationship between consumers and the power system. Moreover, energy generation and storage at the household, local and regional levels reconfigure the energy system logic, e.g. regarding generation and distribution of electricity. This is further supported by the continuous technological innovations and digitization which have opened up further opportunities for citizens and consumers to relate to their energy supply.

The broader conclusions of this dissertation suggest that there is high acceptance of and potential for a more decentralized energy infrastructure based on renewable energies with generation, storage and usage at the local and regional levels. A main result includes the individuals showing interest in various types of involvement: supporting community-based and regional generation, purchasing residential or community storage systems, and choosing renewable electricity tariffs.

Consumers can become more actively involved in a decentralized energy system with generation and storage in proximity to the end-users, and marketing of regionally and locally generated electricity from renewable sources. There are various opportunities for end-users to participate in the energy system either on the individual level through consumer decisions or investments, or on the community level in a collaborative manner by engaging in a community project or by being shareholders. Because consumers have diverse ways of directly engage themselves, the relationship between customers and power companies is changing, as the one-directional system transforms to a bi-directional network with less dependence on power companies. Individuals and households are, hence, likely to have a more prominent role in the future energy system. Looking ahead, participation could positively affect generation sites and overall energy infrastructures in terms of efficiency and acceptance.

Moreover, the results show preferences and opportunities for energy autarky on the household, local and regional levels (see also Engelken, Römer, Drescher, & Welpe, 2016; McKenna et al., 2015; McKenna, Jäger, & Fichtner, 2014). In this regard, there is a tendency towards more self-sufficiency and making your *own energy*. A sense of independence in the household, community, municipality or region has utility for consumers that is not obvious in a traditional energy market logic. Although locally or regionally generated electricity does not exist in a connected grid from a technical point of view – since the path of electricity cannot be determined – it still is a concept that consumers value. This tendency to demand independence should be acknowledged in research and practice. Notably, the falling prices for battery energy storage solutions are revealing themselves to be fertile ground for further consumer participation and new business models in the context of energy autarky.

This dissertation consistently found support and opportunities for bottom-up energy initiatives such as cooperatives, highlighting their role in the German energy system. The conclusions therefore stress the role of, and the trust in, cooperatives. The analyses found opportunities for cooperatives to retail electricity as well as to operate, maintain and control storage systems. Besides the preferences of cooperatives, consumers in the empirical studies consistently favored regional utility companies. Regional ties of energy companies have a positive impact on consumers' choices. These findings are indicators for consumer preferences to encourage local and regional value creation in the energy field.

There is potential to reconfigure the electricity system in Germany, as the empirical analyses showed support for a shift to a more decentralized system. Because centralized energy systems are characterized by few and large power plants, they remain mostly invisible to end-users. In contrast, a decentralized infrastructure based on renewable energies is more visible, as generation, storage and grid infrastructure are spatially distributed and in closer proximity to end-users. Regional generation, community participation and energy autarky can be interpreted as preferences for having a relationship with the energy system – making it less abstract.

4.2. Implications for future research

This dissertation contributes to consumer, energy and sustainability research, particularly in the spaces where they intersect. Furthermore, it has the potential to inform innovation research, since renewable energy technologies – in particular battery storage systems – are considered to be disruptive innovations, and community energy is considered to be a social innovation. The findings add to the literature on sustainable consumption and production and, specifically, pro-environmental behavior. This research provides avenues for further research.

It remains an open question to what extent price is the main driver for all the themes analyzed in this dissertation. In particular, the community energy study did not present price information, but examined financial investment in a rather general way. This could be a reason for the relatively high willingness to participate and invest. Moreover, a social desirability bias could be a factor. Further research should be very precise with regard to costs and include information on risk and return. Moreover, it would need to describe in detail the investigated context as well as the respective pros and cons. For the studies on storage systems and tariff choices, the role of price was examined as part of the choice experiments. However, from a methodological perspective attitude measures and stated preferences methods, as applied in this dissertation, have been criticized since they are only hypothetical and might not translate into actual behavior, owing to the well-established attitude behavior gap (Fennis et al., 2011; Prothero et al., 2011).[34] Still, stated preference measures, such as choice experiments, are widely used to examine willingness to pay (Menges and Beyer, 2015). Louviere et al. (2000) argue that data from stated choice measures can be as good as revealed data, and that there are advantages of using stated over revealed preferences. It is, for instance, possible to investigate new products and services not available on the market, as was the case with the choice experiments in this dissertation. However, examining revealed preferences and actual behavior would help build a deeper understanding of individuals' decision-making. In addition, future research should include deviations from random utility theory, taking bounded rationality into account when measuring preferences.

In the choice experiments, the preferences were rather heterogeneous. As the willingness to pay estimates reflect the preferences of an average consumer, particular segments might differ in their willingness to pay for storage systems or certain tariffs. It can therefore be questioned if applying random parameters models is the best way to analyze the data. Future research could apply latent class models to analyze customer segments aiming to better explain preferences.

Moreover, the essays used different samples to analyze the specific research questions. While the first survey focused mainly on the general population, the second study centered specifically on adopters of a PV system. When analyzing the results, it is necessary to

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[34] Bertrand and Mullainathan (2001), for instance, provide a detailed analysis and critique of subjective survey data (see also Auger & Devinney, 2007).

take into account that the samples consist of different population groups that lean towards either a consumer or a prosumer role. Further research analyzing and comparing different energy-related attitudes and behaviors should ensure similar samples to allow for a direct comparison.

A key difference of the changing energy system is the transforming role of individuals and households, with various opportunities for participating. As the energy system changes, households are assuming different roles, for example as co-owners, producers or members of community initiatives (see also Schot et al., 2016). These diverse roles provide ground for further analyses. This future research should consider individuals and decision-makers in the context of their social environment, e.g. the neighborhood, as energy-related decisions are not only made on the individual but also on the household or community level. In this way, decision-makers might not only consider economic aspects, but also sustainability, social or privacy issues (see also van Vliet, 2012).

The dissertation centered on consumers, but future research should investigate other actors in the energy system, particularly how their roles and relationships change and how they can innovate their business models. Appropriate business models would need to be developed to test if the alternative concepts investigated in this dissertation really work. Moreover, valuable insights for both research and practice could result from analyzing future business models from a corporate perspective using mixed methods. As new roles and relationships develop, the linearity of the electricity value chain alters into a network. This development needs to be taken into account in further analyses and provides new research opportunities. Collaborative business models between different partners require more detailed analyses as they could open up new business opportunities.

The possibilities for collaborative initiatives and joint usage of energy products or technologies set ground for further research. While the willingness to participate and invest was quite high for the community energy project, no stable preference could be found for community storage. The storage concept, either residential or community-based joint usage, did not have a significant impact on consumers' choices. Hence, no stable preferences were found for community-based and joint usage models. Further research could contribute to better understanding these preferences, especially in the light of collaborative consumption. By taking up this theme, conceptual and theoretical studies on joint usage could be valuable for structured analyses of new forms of collaboration and consumption.

If actively involving consumers is seen as an important objective in energy policy, studies could focus on how to incentivize such participation. Research in the fields of energy and sustainability would benefit from a deeper understanding of how to motivate or nudge people to change their energy behavior and to actively participate in the energy system. The findings of this dissertation point to the importance of analyses of how to overcome consumers' disinterest and passiveness, and the lack of motivation to engage in this system. In this regard, better understanding how consumers perceive energy costs could help facilitate energy transitions. Shifting the focus to social and behavioral aspects of the energy system and taking into account findings from consumer research, behavioral studies and psychology can help to realize the full potential of energy technologies.[35]

More generally, attitudes towards and acceptance of energy generation in proximity to end-users are still not comprehensively understood. For instance, there might be interaction effects between proximity and type of energy technology. Future research could center on such effects. Further analyses are needed to better understand public acceptance, and local or regional energy infrastructures in the changing energy system. In addition, future analyses need to take heating and transportation into account, as improvements are needed in all sectors of the energy system.

4.3. Managerial and policy implications

The findings of this dissertation have implications for various actors. With decentralization and new roles for households in the transforming energy system, the relationship between consumers and actors in the energy system is changing in a move away from unilateral dependency to bi-lateral relationships that bring about opportunities and challenges. While energy companies are directly affected by this development, the findings of this dissertation may also help policy-

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[35] Moreover, research and practice could benefit from focusing on energy-related behavior in less developed parts of the world, such as off-grid areas, by applying insights from the aforementioned disciplines (see Schillebeeckx, Parikh, Bansal, & George, 2012).

makers to adjust current regulations and put into place forward-thinking public policies.[36]

4.3.1. Managerial implications

The results of this dissertation may benefit practitioners as they outline new routes for a more decentralized energy system based on renewable energies. The changing energy system has consequences for all stages of the electricity value chain and therefore also for incumbents such as power providers and distribution system operators.

When looking at the future energy system, commentators foresee an *internet of things infrastructure* (Rifkin, 2016, p. 10). Such a development is likely to speed up the transformation towards prosumption and an economy with low or near to zero marginal costs for energy generation, which in turn could cultivate a smarter and more sustainable energy system (see Rifkin, 2016). While incumbents might perceive such developments as fundamental threats, new competitors and companies originally not active in the energy sector could proactively take advantage of this market reconfiguration.

With the rise of clean energy technologies and decentralization, the role of households is changing, resulting in a lower dependence on power providers. Hence, energy companies will experience increased uncertainty as their cost/revenue architecture transforms (e.g., Brunekreeft et al., 2016). This development could further be

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[36] Although this study has focused solely on Germany, the implications might also be valuable for other countries which have similar conditions, e.g. Denmark or the Netherlands (see Yildiz et al., 2015), or that have plans to increase the share of renewables and reconfigure their grid. For instance, insights about battery storage systems might be applicable for future markets such as the UK, California (USA) or Italy.

supported by digitization and the expected expansion of electric mobility. As a result, companies in the energy sector have to rethink their roles and restructure the way they do and cultivate business. Along with these changes, energy companies need to reconfigure their business models, since these are key for market success (see Chesbrough, 2007; Teece, 2010). Currently, these models are relatively diffuse as energy companies are trying to find appropriate strategies for a future energy system (De Fusco, Lorenzi, & Jeanmart, 2016; Richter, 2013). Practitioners can better reframe the configuration of the new energy system by disengaging from the traditional top-down view of the energy system and moving towards a bi-directional relationship with households and individuals in various roles. Focusing on the diverse roles can open up new possibilities and market opportunities for organizations. Along with decentralization and the changing role of households, the role of power providers could change towards more integrated partners providing and managing energy and data, offering products and services, and investing in local and regional energy projects. Developing projects on the local and regional level, and including consumers as co-owners, could improve the relationships and increase public acceptance. This provides new spaces for novel types of business models and market entrants. Aggarwal and Harvey (2013, p. 11) proposed that it *is about delivering the best energy services—not the most electrons—for the least cost.* For instance, integrated supply solutions like combined PV and storage systems with appropriate financing solutions could help build a strong relationship with consumers and reach new customer segments. Moreover, innovations such as blockchain and peer-to-peer solutions, third-party ownership, tenant energy supply concepts, or second life use of batteries could stimulate a dynamic that provides avenues for new business opportunities. Whether consumers accept this strategic transformation of traditional power providers is still open for debate and could also be a relevant theme of future research.

Although a rising share of prosumers generating, storing and using their own electricity might results in *revenue erosion* (Bellekom, Arentsen, & van Gorkum, 2016, p. 9) for energy companies, storage technologies could provide a platform for different actors for new kinds of interacting and collaborating with energy companies. Storage systems also provide opportunities for energy companies to develop new business models by combining different storage applications and by establishing local and regional energy supply concepts. Combining different use cases of battery storage systems can generate value for different actors. Households could be offered a degree of autarky, while operators might benefit through applications like primary control reserve (see Zeh, Müller, et al., 2016). Moreover, a smarter and more decentralized grid enables new types of tariffs, e.g. marketing electricity generated in the community or region, and stored in a community storage system.

The studies showed potential for engaging in the energy supply, particularly for households in more rural and suburban areas. However, much remains to be done to make this participation more accessible in urban areas, where the willingness to participate is lower currently. New ground could be broken in urban areas by developing integrated urban generation, storage and usage solutions such as tenant energy concepts. Particularly, energy innovations for households with lower incomes would be valuable.

The preferences for cooperatives and power providers with regional ties put these in a good position within the future energy system. These preferences could especially encourage cooperatives to enter new business areas, i.e. not only generating energy, but also storing and selling it. Moreover, collaborating with regional partners and community energy projects might provide new business opportunities for incumbents without regional ties – with potential benefits for both parties. More generally, the pressure on energy companies due to changes within the system could open new routes for collaborations between different actors. Partnerships ranging from informal exchange to institutionalized co-operation might stimulate the development of viable solutions and collaborative business models for the future energy system. In collaboration with partners like suppliers or new market entrants, power companies could hope to leverage resources and capabilities, and satisfy consumers' needs more effectively and efficiently. German power providers seem to be relatively open to such collaborations (see Richter, 2013).

Besides the consequences for power providers, the shift towards higher penetrations from decentralized generation puts pressure on the grid, leading to problems such as voltage and frequency issues in the distribution network (Anaya & Pollitt, 2015; Passey et al., 2011). Distribution system operators and regulators are being challenged by the developments towards decentralization and energy storage on the local level (Ruester, Schwenen, Batlle, & Pérez-Arriaga, 2014). With a rising share of households generating and storing electricity, distribution system operators now have traditional consumer but also prosumer households that they must connect to. The developments in the energy market emphasize the role of managing local networks and, more significantly, have an impact on the business models of grid operators, which have to adjust to the new conditions (Bellekom et al., 2016; Lehr, 2013).

4.3.2. Policy implications

On the policy level, this dissertation contributes to better understanding of consumer behavior and the various roles of individuals and households in the transforming energy system which need to be accounted for when developing policies in the energy and consumer field. Moreover, from a policy perspective, this work offers insights on technological change in the power sector and the diffusion of clean technologies and electricity.

Public policies and regulations must set an appropriate framework for a future energy system with more actively involved households and innovative business models. Policy-making needs to keep up with the changes observed in the market and adjust the rules, regulations and incentives accordingly. Particularly, reassessing the legal and regulatory framework for storage systems seems needed to enable community-based and other innovative storage concepts. Policy-makers should recognize the diverse roles of households – as they are not only consumers, but also producers, investors and societal actors – and the transforming relationship between power companies and consumers. Forward-thinking policy-making could be well-served by taking into account these aspects and operating with a comprehensive perspective (see also Newcomb et al., 2013). On the level of consumer policy, public policies might focus more on individual behavior taking into account social aspects and behavioral insights, e.g. norms and peer effects.

A rising share of households generating electricity leads to challenges regarding the *socialization of connection costs* (Anaya & Pollitt, 2015, p. 484). As more households engage in generating and using their own electricity, the connections costs are distributed among less kilowatt hours. As a result, the network charges increase and especially households not generating electricity may have to pay higher bills (Maubach, 2015; Quoilin, Kavvadias, Mercier, Pappone, & Zucker, 2016). This development sparked a debate on fairness issues in Germany. Future regulation of the connection and grid fees needs to consider such developments.

Moreover, the sustainability of autarky movements on the local or regional level needs to be evaluated in detail. Policy-makers should carefully analyze the effects of such initiatives taking into account the energy system as a whole before deciding if they should be supported. Similarly, if such initiatives are undesirable, one can question the labelling of regionally generated electricity recently introduced in Germany, as such a label indicates to some extent that regional electricity is better. Furthermore, although this dissertation found preferences for regionally generated electricity and the label was introduced to increase public acceptance and the further expansion of renewable energies (BMWi, 2016b), it is open to discussion whether this can be achieved and whether such a label helps consumers to make informed decisions – since, in a physical sense, regionally generated electricity cannot be differentiated from other types of electricity. Moreover, the interest in and acceptance of a regional energy label is currently unclear as even the present energy certification and labeling is complex for consumers.

The new opportunities for individuals to participate in the energy system can help increase consumer involvement. This is particularly relevant since electricity is a product with a high importance but low involvement for households. A more active role for households can be a first step towards more conscious consumption of electricity and more energy-efficient and sustainable behavior.

As the energy system becomes more decentralized, the traditional electricity value chain alters into a network in which the roles regarding production, consumption, and distribution are newly defined. This dissertation has shed light on previously neglected areas of research, i.e. on the role of households in the energy system with a focus on participation in community energy, purchase of a battery storage system and tariff choice. It has provided insights into consumers' attitudes and preferences in the changing German electricity system. It seems evident that the involvement and participation of households in the energy system has the potential to significantly increase in the near future, leading to novel opportunities and challenges. Making use of not only technological, but also social innovations such as joint usage, and consumer empowerment, can help tap the full potential in the move towards a more sustainable energy system.

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Appendices

Appendix 1: Output of the mediation analyses: Steps 1-4 *(ESSAY I)*

Model	Dependent variable	Independent variables	Coeff. b	SE	R^2
Step 1	Trust	Community identity	0.8486***	0.0863	0.1375
		Environmental concern	-0.2492	0.1394	
		Age	-0.0001	0.005	
		Gender (female)	-0.3854*	0.1592	
		Net household income	0.1504***	0.0428	
		Type of community	-0.1656	0.1576	
		Ownership renewable energy system	0.4242*	0.2075	
		Constant	3.4345***	0.6464	
Step 2	Social norms	Trust	0.0624***	0.0158	0.1179
		Community identity	0.2192***	0.0441	
		Environmental concern	-0.1311	0.068	
		Age	-0.0121***	0.0024	
		Gender (female)	0.1543*	0.0777	
		Net household income	0.0223	0.021	
		Type of community	0.1381	0.0768	
		Ownership renewable energy system	0.3404***	0.1012	
		Constant	3.3507***	0.3193	
Step 3	Willingness to participate	Trust	0.1539***	0.0238	0.2703
		Social norms	0.4110***	0.0486	
		Community identity	0.0605	0.0667	
		Environmental concern	0.6624***	0.1017	
		Age	-0.0038	0.0037	
		Gender (female)	-0.4732***	0.1163	
		Net household income	0.1592***	0.0313	
		Type of community	0.2478*	0.1148	
		Ownership renewable energy system	0.6922***	0.152	
		Constant	-1.2998*	0.5038	
Step 4	Willingness to participate	Community identity	0.3029*	0.0668	0.1704
		Environmental concern	0.5638***	0.1079	
		Age	-0.0088*	0.0039	
		Gender (female)	-0.4790***	0.1232	
		Net household income	0.1953***	0.0331	
		Type of community	0.2748*	0.122	
		Ownership renewable energy system	0.9083***	0.1606	
		Constant	0.6939	0.5004	

Appendix 2: Output of the mediation analyses: Total, direct, and indirect effects *(ESSAY I)*

Total effect of community identity on willingness to participate					
Effect	SE	t	p	LLCI	ULCI
0.3029	0.0668	4.5342	0.000	0.1718	0.434
Direct effect of community identity on willingness to participate					
Effect	SE	t	p	LLCI	ULCI
0.0605	0.0667	0.9064	0.3649	-0.0704	0.1914
Indirect effect of community identity on willingness to participate through trust					
Effect	Boot SE			LLCI	ULCI
0.1306	0.0266			0.0801	0.1831
Indirect effect of community identity on willingness to participate through social norms					
Effect	Boot SE			LLCI	ULCI
0.0901	0.0223			0.0491	0.1395
Indirect effect of community identity on willingness to participate through trust and social norms					
Effect	Boot SE			LLCI	ULCI
0.0218	0.0069			0.0100	0.0383

Note: n iterations = 1000; * $p < 0.05$. ** $p < 0.01$. *** $p < 0.001$;

Appendix 3: Example of a choice set for battery storage systems *(ESSAY II)*

	Option A	**Option B**	**Option C**	**Option D**
Location of the storage system	In your house	In your house	In your neighborhood	I don't choose any of the displayed options.
Costs and ownership mode	12.000 € one-time payment Ownership	6.000 € one-time payment Ownership	85€ per month for 10 years Use rights	
Payback period	18 Years	6 Years	-	
Average level of autarky regarding electricity	100%	25%	75%	
Control & provision of services for grid	Own control by default	External control by default	External control by default	
Partner companies (e.g. maintenance and control)	Nationwide electricity supplier	Battery operator	Regional electricity supplier	
I choose:	☐ A	☐ B	☐ C	☐ D

Note: This example corresponds textually, but not graphically, to a presented choice set in our study.
Example translated from German

Appendix 4: Example of a choice set for electricity tariffs *(ESSAY III)*

	Tariff A	**Tariff B**	**Tariff C**
Electricity mix	15% solar, 85% water	47% coal, 17% nuclear, 11% natural gas, 9% wind, 8% biomass, 4% solar, 4% water	47% coal, 15% natural gas, 15% wind, 12% biomass, 5% solar, 6% water
Monthly electricity cost per person in Euro	40,00€	28,00€	23,00€
Percentage of locally produced electricity within a radius of 20 km	33%	100%	66%
Power provider	National power provider	Local energy cooperative	Regional power provider (e.g. municipal utility)
I choose tariff:	☐ A	☐ B	☐ C

Note: This example corresponds textually, but not graphically, to a presented choice set in our study. Example translated from German