Valuing improvements in electricity supply using discrete choice experiments: Preferences of private households in India and Germany

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Dipl. Vw. Julian Sagebiel

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Präsident der Humboldt-Universität zu Berlin

Prof. Dr.-Ing. Dr. Sabine Kunst

Dekan der Lebenswissenschaftlichen Fakultät

Prof. Dr. rer. nat. Richard Lucius

Gutachter

(1) Prof. Dr. Markus Hanisch

(2) Associate Professor Dr. Jos Bijman

(3) Prof. Dr. sc. agr. Reiner Doluschitz

I dedicate this thesis to my daughter Jula and my son Karl.

Declaration

I hereby declare that except where specific reference is made to the work of others, the contents of this dissertation are original and have not been submitted in whole or in part for consideration for any other degree or qualification in this, or any other university. This dissertation is my own work and contains nothing which is the outcome of work done in collaboration with others, except as specified in the text and acknowledgments. I acknowledge that copyright of published works contained within this thesis resides with the copyright holders of those works.

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Julian Sagebiel
April 2017

Acknowledgements

When I started my employment at Humboldt-Universität in 2009, I was not familiar with interdisciplinary and applied research. My education until then focused on theoretical-economic modeling. However, having worked for two years in a multidisciplinary research project, in 2011, I decided to write a methodical and empirical Ph.D. thesis in the subjects of energy and applied consumer behavior. At first, I was unsure whether I could cope with the new challenges: Field work in India, interdisciplinary research, and policy-oriented work. By now, nearly five years after I have submitted my Ph.D. proposal, I am convinced that it was the right step. It did not only enhance my knowledge in applied consumer research in energy, but I learned to examine problems from different perspectives. More importantly, I would have never had the chance to get to know all the fine people who enriched both my personal development and my engagement in scientific work. This dissertation would not have been possible without the tremendous support from so many people who I learned to know within my time at Humboldt-Universität and the Sustainable Hyderabad project.

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Abstract

In order to design electricity markets to simultaneously reduce the share of fossil fuels in energy production and meet the increasing demand for electricity, knowledge on consumer preferences is necessary. The goal of this cumulative dissertation is to contribute to the understanding of preferences of private households for electricity supply attributes in different contexts. The guiding research questions are 1) what attributes of electricity determine private household electricity supply preferences and 2) how do electricity preferences differ between people and contexts.

I address the research questions in four papers which have in common the application of the discrete choice experiment method to elicit preferences:

In **Paper 1** I review statistical methods to compare two frequently applied models, the random parameters logit and the latent class logit. The methods presented here can be readily used by other researchers and practitioners to better understand model performance which ultimately contributes to improving model choice in applied energy research.

Based on the empirical findings of Paper 1, **Paper 2** identifies preferences of private households in Hyderabad in India for electricity supply quality. The results indicate that willingness to pay for improvements are, on average, rather low. However, the preferences strongly vary between subjects.

Papers 3 and 4 investigate preferences of German private households. In **Paper 3**, the respondents stated their preferences for the organization of the electricity distribution company under different renewable energy scenarios. It turned out that most people are willing to pay more for electricity supplied by municipally-owned companies and cooperatives. This additional willingness to pay increases disproportionally when the share of renewable energy is high. The paper identifies non-profit orientated distribution companies as potential drivers of the energy transition.

Paper 4 investigates the determinants for the success of energy cooperatives in Germany. The results indicate that the governance of distribution companies impacts the choices of private households for electricity supply contracts. Especially, people preferred cooperative-like governance attributes. However, the willingness to pay for governance attributes was significantly lower than the willingness to pay for increases in renewable energy.

The overall results show that preferences and willingness to pay values for improvements in electricity supply exist but are heterogeneous. While large willingness to pay values for further expansion of renewable energy sources exist in Germany, private households from India are concerned about the physical power quality and have low willingness to pay for improvements. In both countries, the majority of people prefer state-owned distribution companies over private companies.

Policy makers should provide options for consumers with respect to tariffs and technology. Competitive electricity markets should be accessible for citizen-owned companies and cooperatives and regulatory policies should remove entry barriers for smaller companies. Such companies are more likely to facilitate an energy transition and increase the share of renewable energy.

Zusammenfassung

Um Strommärkte so zu konzipieren damit sie sowohl zur Verringerung der Nutzung fossiler Brennstoffe als auch zur Deckung des steigenden Energiebedarfes beitragen, ist Wissen über die Präferenzen der Konsumenten notwendig. Die vorliegende kumulative Dissertation untersucht Präferenzen für Elektrizitätsattribute von privaten Haushalten und trägt zu einem tieferen Verständnis dieser in unterschiedlichen Kontextsituationen bei. Die zentralen Fragestellungen sind 1) welche Attribute spielen bei der Stromversorgung privater Haushalte eine Rolle, und 2) wie unterscheiden sich Präferenzen zwischen Menschen und zwischen Kontexten. Die Bearbeitung dieser Forschungsfragen erfolgt in vier wissenschaftlichen Artikeln. Discrete Choice Experimente werden als Methode zur Messung von Präferenzen herangezogen.

Der erste Artikel betrachtet statistische Methoden um die zwei am häufigsten angewandten Modelle – das Random Parameter Logit und das Latent Class Logit Modell – zu vergleichen. Der Artikel trägt dazu bei, den Prozess der Modellwahl zu verbessern und für die angewandte Forschung im Energiebereich anzupassen.

Basierend auf den empirischen Ergebnissen des ersten Artikels untersucht der zweite Artikel die Präferenzen von privaten Haushalten in Hyderabad, Indien mit besonderem Fokus auf die physische Qualität der Energieversorgung. Die Ergebnisse deuten auf eine geringe Zahlungsbereitschaft der Konsumenten hin. Jedoch unterscheiden sich die Präferenzen der Haushalte.

Die Artikel 3 und 4 basieren auf Datenerhebungen in Deutschland. Im dritten Artikel werden die Präferenzen privater Haushalte hinsichtlich der Organisationsform von Stromanbietern untersucht. Die Ergebnisse zeigen, dass die Kunden bereit sind mehr zu zahlen, wenn die Stromversorgung von Genossenschaften oder Stadtwerken übernommen wird. Die Zahlungsbereitschaft für Strom von diesen Anbietern erhöht sich vor allem in Kombination mit einem hohen Anteil an erneuerbarer Energie. Gemeinnützige Unternehmen können hier als die Triebfedern der Energiewende identifiziert werden.

Der vierte Artikel betrachtet die Erfolgsfaktoren von Energiegenossenschaften in Deutschland. Die Ergebnisse zeigen, dass die Governance des Stromanbieters die Zahlungsbereitschaft für Strom beeinflussen. Insbesondere Genossenschaften werden den großen Privatun-

ternehmen und Aktiengesellschaften vorgezogen. Im Vergleich sind Zahlungsbereitschaften für erneuerbare Energien jedoch deutlich höher.

Konsumenten sind bereit, für eine verbesserte Stromversorgung zu zahlen. In Deutschland kann eine hohe Zahlungsbereitschaft für erneuerbare Energien beobachtet werden. In Indien befassen sich Haushalte eher mit der physischen Stromqualität und zeigen insgesamt geringere Zahlungsbereitschaften für Verbesserungen auf. In beiden Ländern bevorzugen die Konsumenten staatliche Unternehmen gegenüber privaten Anbietern.

Politische Entscheidungsträger und Versorgungsunternehmen sollten Optionen in Bezug auf Tarifmöglichkeiten und Technologien ausweiten. Konkurrenzfähige Strommärkte sollten sowohl Genossenschaften als Geschäftsmodell zulassen als auch solche Regulierungen abbauen, die kleinen Unternehmen den Zugang zum Markt erschweren.

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Chapter 1

Introduction

> Perhaps the most important aspects of consumer behavior relevant to an economy [...] are those of consumer reactions to new commodities and to quality variations. Traditional theory has nothing to say on these. (Lancaster, 1966, p.133)

1.1 Current Challenges in the Electricity Sector and the Role of the Consumer

Many developing and emerging economies lack sufficient electricity supply. About 17% of the world's population have no access to electricity, adversely affecting health, education, and food security (UN-Energy, 2005; World Bank, 2015). At the same time, worldwide electricity production accounts for 25% of total carbon dioxide emissions, being a key culprit in the process of climate change (International Energy Agency, 2014b). Thus, finding solutions that allow for increased electricity production while simultaneously reducing carbon dioxide emissions has become a major global challenge (Geden and Beck, 2014; UNDP, 2002).

Around the world, policies at different scales have recently initiated a transition towards decentralized electricity production from renewable energy sources so as to decrease the electricity supply gap in a climate-friendly way (Bhide and Monroy, 2011; Field et al., 2014). By 2014, 46 countries had established policies to promote renewable energy (REN21, 2015). Yet, estimated increases in electricity production from fossil fuels still emit too much carbon dioxide to reach the $2°C$ goal (International Energy Agency, 2014a).

Electricity consumers are directly affected by these developments in the sense of being the bearers of the consequences (e.g., changes in prices or electricity quality), but they can also influence the process through their electricity purchasing choices. The following examples seek to explain the role of the consumer and the current situation in the electricity sectors of

two different contexts: India, as an example of an emerging economy, and Germany, as an example of an industrialized country.

India presently has the highest share of growth in electricity demand in the world (International Energy Agency, 2014a). In spite of several liberalization efforts, however, the electricity sector is still mainly controlled by the government and is marked by insufficient electricity grid infrastructure. Retail electricity rates often do not recover production costs, leading to high subsidy payments for electricity which affect the overall economic performance of the country (Williams and Ghanadan, 2006). Various governmental policies have been aiming towards increasing electricity production as well as renewing and extending grid infrastructure. Although many of these policies incentivize and support renewable energy production, the largest share of additional production still comes from coal, it being the cheapest energy source (Banerjee, 2014; Central Electricity Authority, 2004). Yet consumers bear the consequences, suffering from air pollution and limited availability of electricity (Ahuja, 2016). Of the country's 1.3 billion inhabitants, 240 million Indians have no access to electricity (International Energy Agency, 2014a), and most households that have an electricity connection face frequent power cuts and voltage fluctuations (Tongia, 2007). The main challenge in India, then, is to satisfy increasing electricity demand, including increased production and infrastructural investments, while simultaneously reducing carbon dioxide emissions and restructuring the market to lower financial burdens on the government (Bhide and Monroy, 2011).

In contrast, in Germany, one of the richest countries in the world, there is no excess demand for electricity. Having heavily invested in renewable energy, Germany is regarded as a pioneer in the worldwide energy transition, with a share of about 27% renewable energy in its electricity mix in 2015 (BMWi, 2015; Wassermann et al., 2015). Its liberalized market structure, with a large number of retail distribution companies, has led to a wide array of contract choices for consumers, including options for regionally produced renewable energy and participation (Schmid et al., 2016). Consumers are changing electricity-distribution companies not only to minimize costs but also to foster change, increase the share of renewable energy or support a specific distribution company whose goals they identify with (Devine-Wright, 2014; Kaenzig et al., 2013). Thus, a market for electricity from renewable energy sources has emerged, mainly because consumers have revealed themselves as being willing to pay a premium for it voluntarily. However, the ambitious targets for reducing carbon dioxide emissions set by the German government require new strategies to further increase the share of renewable energy (Gährs et al., 2015).

To achieve a sustainable energy transition, meaning here sufficient worldwide electricity supply with greatly reduced carbon dioxide emissions, it appears that understanding consumer

preferences in the electricity sector is of crucial importance for policy makers at various scales for at least two reasons:

First, in the electricity sector, characterized by externalities and economics of scale, governmental intervention is often required (Müller and Rommel, 2011; Train, 1991). Governments have limited resources and should allocate them where they can create the highest net-benefits. The most common approach for identifying optimal allocation is cost-benefit analysis (Wolfson, 2015), the quality of which depends greatly on available information regarding consumer preferences and valuation. As private households are often affected by the outcomes of government policy, it is important to understand their preferences.

Second, it is widely recognized that consumers have been stimulating the ongoing energy transition (OECD, 2009; Schmid et al., 2016), and their actions have impacts on the extension of renewable energy production. New incentives to promote renewable energy and participation are, then, only likely to be effective if they are embraced by consumers. Thus it would seem that acquiring a better understanding of their preferences could be helpful for designing such incentives (Yildiz et al., 2015).

Information on consumer preferences are often not directly observable, however, because electricity markets are not completely competitive, so market prices cannot be used to calculate welfare changes (Freeman III et al., 2014). Additionally, electricity is a heterogeneous good from the consumer perspective. It is not only electricity availability that matters but its attributes, such as the share of renewable energy comprising it, location of production, duration of scheduled and unscheduled power cuts or frequency of voltage fluctuations.

1.2 Electricity Attributes: Governance, Physical Quality, Externalities and Location

In order to gain a systematic overview of the salient attributes of electricity, I have categorized them into four domains – distribution company, physical quality, externalities and location – which I will refer to in the following as *who*, *what*, *how* and *where*. In the remainder of this section, I seek to show how each domain affects consumers and their preferences. Although the domains are mutually exclusive, they are not necessarily independent from each other, as they interact and influence each other, and their importance in consumer choices differs according to context.

Distribution companies can be described with reference to their attributes and can be distinguished according to their organizational form (e.g. profit-oriented, state-owned, cooperative) or governance and internal policies (e.g., profit distribution, price transparency).

Consumers have preferences for different types of the distribution companies. They may, for example, not perceive a particular company as being 'credible' because it has only recently entered the market, thereby bearing the risk of potential bankruptcy. Another company's lack of effort towards reducing carbon dioxide emissions or its treatment of employees can result in it gaining a bad reputation and, thus, not being preferred by some consumers. Consumers may also have preferences regarding governance structures within distribution companies, such as their pricing policies or decision-making procedures. A company that reveals its pricing policy may be preferred by consumers to other companies. The existing literature, however, has hardly taken note of the link between consumer preferences and company governance structures, which I subsume under the domain of *who*.

Physical electricity quality directly affects consumers and includes attributes such as frequency and duration of power cuts and voltage stability. In countries where demand for electricity exceeds supply and grid capacity is limited, these attributes are especially relevant. In such areas, private households often suffer from non-availability of electricity for cooling in summer or lighting in the evening. Some consumer groups may be more affected by quality problems than others. It would seem obvious that higher quality is preferred by most consumers, but what attributes are most important to them and what the trade-offs between different attributes are has been until now largely unexplored, and the literature regarding private household preferences is limited to a few studies focused on power cuts (Abdullah and Mariel, 2010; Amador et al., 2013; Hanisch et al., 2010). I subsume physical quality and its attributes under the domain *what*.

Externalities are generally related to the various sources used in the generation of electricity, which can be roughly grouped into two main categories: conventional electricity production means use of fossil fuels, whereas renewable electricity relies on solar, biomass and wind, among many others. For some consumers, the share and sources of renewable energy used in a distributor's mix matter, but increasing this share generally comes at a significant cost. In Germany, private households already mandatorily pay about 20% of their end-use price towards renewable energy, and about 11% of households voluntarily add a premium for further extension of renewable energies (UBA, 2013b). Unlike the previously mentioned domains, externalities related to electricity generation are perhaps the most frequently covered domain in the literature, and several recent theoretical and empirical studies have shown that, to an certain extent, consumers are willing to pay to reduce externalities from electricity production (Ma et al., 2015; Menegaki, 2008; Soon and Ahmad, 2015; Sundt and Rehdanz, 2015). I subsume the externalities under the domain *how*.

With regard to the electricity sector, location refers to where companies' headquarters and places of production are situated. Positive and negative externalities are also linked to the

proximity of distribution companies. For example, close-by distribution companies may have positive employment effects that benefit local economies. Meanwhile, negative externalities of local production include the visibility of wind parks (Meyerhoff, 2013). In the literature, it has been found that people prefer proximate distribution companies (Kaenzig et al., 2013), but also here, the number of relevant studies is relatively low. I subsume location under the domain *where*.

The relevance of the four just-described domains differs according to the context in which the consumer is embedded. I define context as the interconnected conditions, including socio-economic, cultural and geographic variables, in which electricity consumption takes place. In order to better understand such contextual differences, the present dissertation focuses on two case studies: one from India, representing an emerging economy, and one from Germany, as an example of an industrialized country. In India, consumers are mostly concerned about the physical aspects of electricity quality, and preferences related to reducing externalities are of secondary rank (Hanisch et al., 2010). Meanwhile, in Germany, the physical quality of electricity is perceived by the consumer to be at a nearly-optimal level –so much so that it is taken for granted – and basic needs related to electricity are generally easily satisfied. Consequently, questions regarding externalities and location have become more important.

In addition to differences in preferences due to context, people with differing social status, socio-demographic characteristics, attitudes and perceptions may have different preferences. How preferences differ within a context can have implications for aggregated preferences within it (Greene and Hensher, 2003).

To sum up, consumer preferences regarding electricity may be shaped by the four domains *who, what, how and where*, which themselves can vary according to context. The literature does not have much to say about the *who* and *where*, while the *what* has been relatively well covered. The *how* has been researched most frequently, and a variety of meta-studies summarizing relevant results already exist. Table 1.1 overviews these domains, providing examples of attributes important to consumers and how well they have been covered in the literature.

1.3 Theoretical Framework and Method

The theoretical framework developed for the present study seeks to explain the process of how consumer choices in the electricity sector are made, based on the neoclassical paradigm of preferences and utility. As the neoclassical approach does not explain differences in preferences between people and seems inadequate for describing the complexity of the domains *who*, *what*, *how* and *where* of electricity, I have extended it using theories

Domain	Attributes	Literature Coverage
Who	Organizational form Price transparency Decision making	No studies available
What	Power cuts Voltage fluctuations Response time	Some studies (Abdullah and Mariel, 2010; Amador et al., 2013; Hanisch et al., 2010)
How	Share of renewable energy Sources of renewable energy	Numerous studies (Ma et al., 2015; Menegaki, 2008; Soon and Ahmad, 2015; Sundt and Rehdanz, 2015)
Where	Location of distribution company Location of production	Few studies (Kaenzig et al., 2013; Meyerhoff, 2013)

Table 1.1 Domains and examples of attributes relevant to electricity consumers

developed by Maslow (1943) and Lancaster (1966). Maslow's *hierarchy of needs* can enhance understanding of preference differences across individual people and contexts, whereas Lancaster's *household production framework* relates attributes to goods, which is key for modeling electricity preferences.

People have needs. But Maslow (1943) argues that higher needs, such as esteem, become truly relevant only after the most fundamental needs have been satisfied[1]. Needs are embedded into the contexts in which consumers make their choices. In different contexts, needs can be differently satisfied. They can be satisfied through services, which can be concrete (e.g. temperature regulation), but also through more complex phenomena (e.g. charitable giving). In combination with other variables (e.g., individual income, attitudes, perceptions), people construct preference relations for services (Costanza et al., 2007). A consumer cannot buy services themselves on markets, but she can buy combinations of goods that can help to accomplish such services to the required level. In other words, goods are inputs to produce services (Lancaster, 1966), with each good consisting of a number of attributes or attribute levels. There are also ordinal utility functions that assign numerical values, producing rankings for alternative combinations of goods (Mas-Colell et al., 1995). Each consumer maximizes their own utility function under constraints, leading to a demand function, which then determines his choices for goods. Because goods are described by

[1]Maslow's approach has often been criticized and modified (Tay and Diener, 2011). However, for the purposes of this study, it is sufficient to understand its basic logic, which is still generally accepted in the social sciences.

their attributes, demand functions can be expressed in attribute space, meaning that they can indicate demand for attributes or attribute levels in relation to prices and other variables.

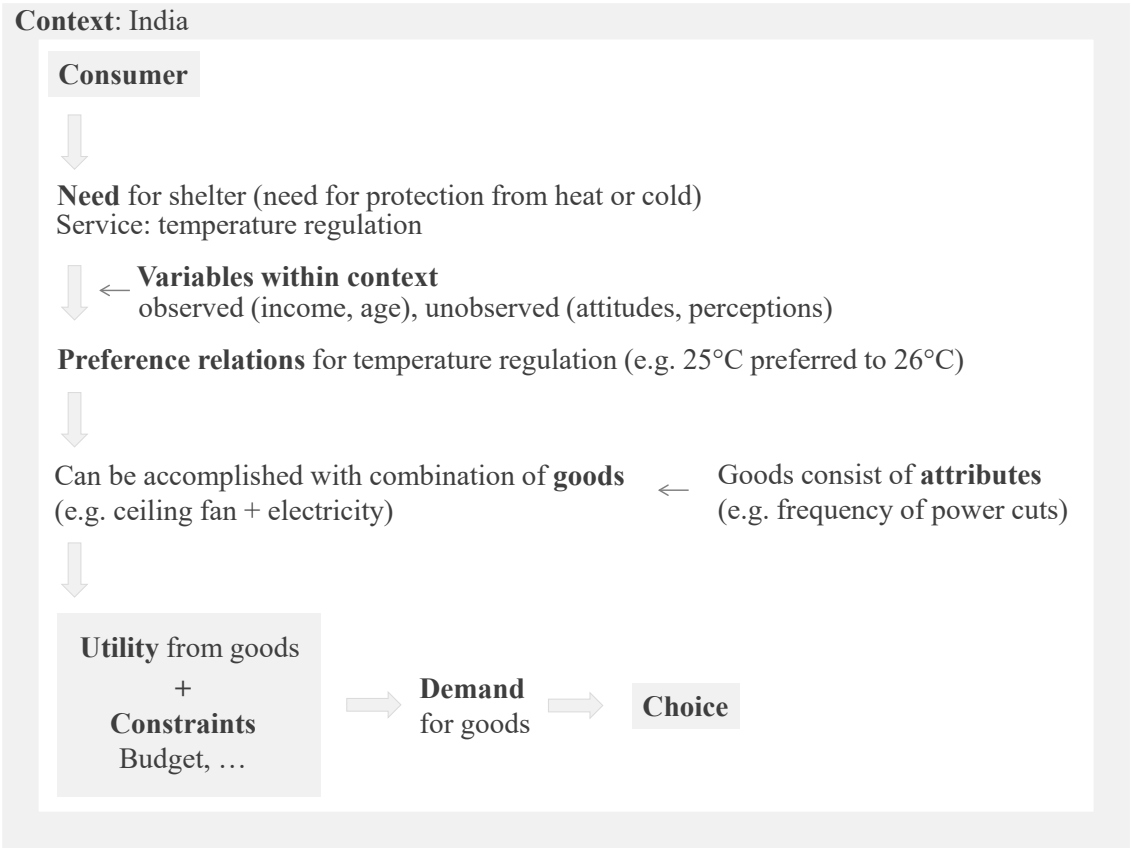

Fig. 1.1 Theoretical framework exemplified via cooling devices in the Indian context

The following example seeks to illustrate how application of this framework works in the Indian electricity sector (see Fig. 1.1). In India, many people struggle to satisfy their need for shelter, which includes protection from very hot or cold temperatures. Here, the required service is temperature regulation. Depending on other variables (average outside temperature, individual perception of heat), preference relations for room temperature are formed (e.g. $25°C$ is preferred to $26°C$, $20°C$ is preferred to $19°C$ and so on). Temperature regulation can be produced through various combinations of goods that are traded on a market: air conditioners in combination with electricity, ceiling fans in combination with electricity, or special ways in which houses can be constructed (without any electricity required). Each good consists of different attributes, such as how fast and to what extent an air conditioner can regulate room temperature. Electricity is also a good that can be distinguished according to its attributes. In order to attain an optimal temperature level, consumers need to purchase

marketed goods that are largely conditional on the attributes of electricity. In this example, the domain *what* is relevant. For an air conditioner, stable electricity supply is more important than for a ceiling fan. Thus, a consumer with an air conditioner is likely to have a stronger preference for stable voltage than a consumer who has a ceiling fan, all other things being equal.

This example reveals some challenges in measuring electricity preferences. In India, voltage-level fluctuations are exogenously determined. If consumers were to have a choice, then, it is likely that they would chose a lower level of voltage fluctuation and would be willing to pay for it. As the resulting choice is not observable, however, it is not possible to infer information on such consumer preferences and willingness to pay. This information is, nonetheless, a critical input for designing efficient policies in the electricity sector, as discussed above.

Elicitation of such unobservable preferences can be approximated using non-market valuation methods (Bateman et al., 2002). Various non-market valuation methods exist and can be distinguished into revealed and stated preference methods. Revealed preference methods take advantage of observable choices regarding market goods that are substitutes or complements for non-market goods. Most prominent here are the hedonic pricing and travel cost methods. In contrast, stated preference methods do not require market observations. The idea is to hypothetically ask respondents to state their appreciation, often expressed as willingness to pay, for a non-market good. Currently, the most widely used stated preference methods are contingent valuation and discrete choice experiments.

In this dissertation, I employ discrete choice experiments, as they can be used to estimate preferences for each attribute of electricity independently. Discrete choice experiments are survey-based; for the purposes here, respondents choose repeatedly between hypothetical electricity contracts that differ in their attributes. The observed choices are then used to estimate preferences and willingness to pay values for the attributes discussed above by regressing the attributes on choice. Discrete choice experiments have several advantages compared to other revealed and stated preference methods. Especially for research on preferences in the electricity sector, the following advantages are relevant: First, discrete choice experiments enable investigation of attribute levels that do not yet exist. In India, for example, a large share of renewable energy in the electricity mix is not readily available to consumers. Second, it allows inference of preferences for any possible combination of attributes and interaction effects between attributes. Third, advanced models can incorporate the observed and unobserved heterogeneity of preferences, capturing differences between people based on socio-demographic variables as well as differences in variables that are unknown to the researcher. The formal theoretical background of discrete choice experiments

is explained in more detail in Appendix A, and the discrete choice models used in the individual papers of this dissertation are presented in the respective chapters.

1.4 Research Questions and Dissertation Structure

This dissertation consists of four papers that have used discrete choice experiments to contribute towards better understanding of private household preferences regarding electricity attributes in different contexts. The data come from three discrete choice experiment surveys: one conducted in India and two in Germany. The first paper is a methodological review that serves as the basis for the statistical analysis done for the remaining three papers, which are all policy-oriented. One methodological and one empirical research question have guided this research, with the empirical one being divided into two sub-research questions, one for each geographical context. Figure 1.2 outlines the structure of the dissertation.

> **Methodical research question:** How do electricity preferences differ within a single context?
>
> **Empirical research question:** What domains and attributes determine private household electricity preferences?
>
> > **Empirical sub-research question 1:** What domains and attributes determine private household electricity preferences in India?
> >
> > **Empirical sub-research question 2:** What domains and attributes determine private household electricity preferences in Germany?

The **methodological research question** is related to the observation that preferences can and generally do vary between people situated in the same context. Some of this variation may be explained by observed variables such as age or household size. For example, Indian families with small children in the household have to rely more on temperature regulation than a single-person household, which will lead to a stronger preference among the former for fewer power cuts. Such *observed preference heterogeneity* can be inferred by inclusion of relevant variables into choice models. Yet there may remain variation between respondents that cannot be explained by observed variables. The commonly employed inclusion of *unobserved preference heterogeneity* in discrete choice models can lead to several alternative model specifications, with each implying a different pattern of preference distribution (Train, 2009). In order to better understand the implications of these models, **Paper 1** reviews available and easy-to-implement statistical methods for model choice. It then

develops an agenda of procedures to identify appropriate model specifications, exemplifying it via a statistical comparison of the two most frequently applied discrete choice models: random parameters logit and latent class logit. Both models have in common that they incorporate unobserved preference heterogeneity but differ in their assumptions regarding how preferences are distributed across the population. The random parameters logit model assumes a continuous parametric distribution of preferences, described, for example, using a normal or log-normal distribution function. In contrast, the latent class logit model uses a non-parametric distribution, leading to a finite number of preference classes.

The **empirical research questions** are addressed in the remaining three papers. **Paper 2** tackles the **first empirical sub-research question** and is aimed at guiding policy makers in India regarding which existing deficits in electricity supply are considered to be most harmful to private households, which groups are being most severely affected and how the households would like the electricity market to be (re)organized. My co-author – Kai Rommel – and I investigated preferences regarding 1) duration of scheduled and unscheduled power cuts, representing the *what* 2) share of renewable energy, representing the *how*; and 3) distribution company's organizational form – currently a government-owned monopoly – representing the *who*. The results suggest, first, that preferences strongly differ across the population and, second, that the overall willingness to pay is rather low for most consumer groups, with only a small percentage of consumers expressing a high willingness to pay, especially for reducing power cuts and increasing the share of renewable energy. Concerning the *who*, most private households favor the status quo situation, meaning a government-owned distribution company.

Papers 3 and 4 are related to the **second empirical sub-research question**. My co-authors – Jens Rommel and Jakob Müller – and I applied discrete choice experiment data from Germany, seeking to address the *who*, *how*, and *where*. As the reasons why people have preferences regarding the governance of electricity distribution companies are not as straightforward as for the other domains, we borrowed from New Institutional Economics theory to extend the theoretical choice framework. **Paper 3** investigates the relationship between the organizational form of distribution companies (private, cooperative, municipality owned) and renewable energy share. Using Akerlof's 'Market for Lemons' (Akerlof, 1970), we develop a hypothesis that distribution company governance becomes more important to consumers when the share of renewable energy in offered energy mixes is great. The results here show, first, that willingness to pay for more renewable energy is higher when it is supplied by municipality-owned and cooperative distribution companies and, second, that this difference increases with an increasing renewable energy share. Last, **Paper 4** studies the governance attributes of cooperatives in more detail. Here, Transaction Cost

Economics serves as the theoretical basis. Private households can reduce transaction costs related to electricity supply by becoming members of a cooperative that is characterized by a democratic structure (one member, one vote) and offers participation possibilities. Further, most cooperatives exhibit a more transparent pricing policy and are more regionally focused than large investor-owned companies. The results here show that, apart from renewable energy share, it is especially price transparency and participation that affect choice and, thus, seem to be the most important characteristics of energy cooperatives for consumers.

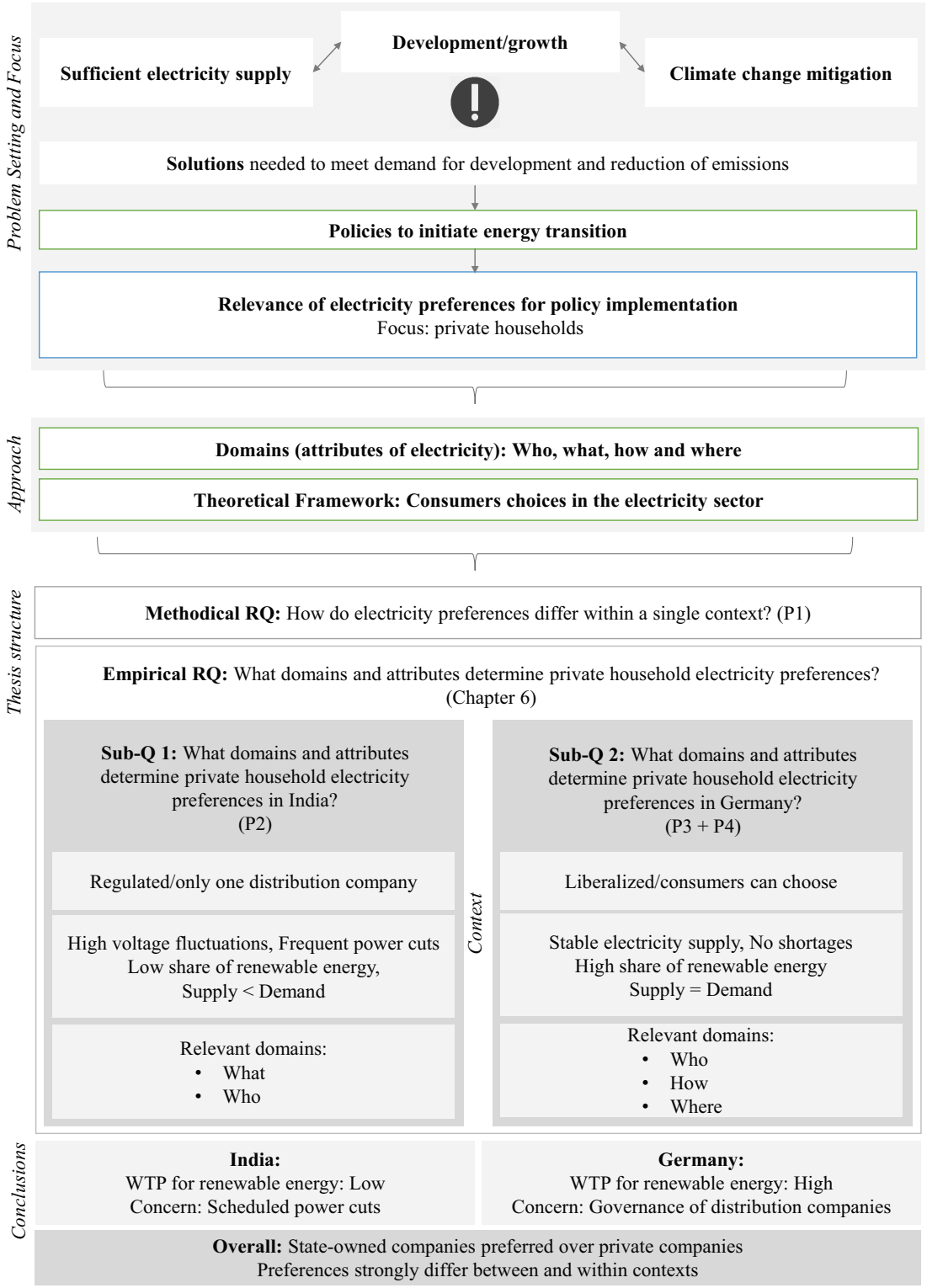

Fig. 1.2 Outline of Dissertation

Chapter 2

Preference Heterogeneity in Energy Discrete Choice Experiments (P1)

Full Title: Preference Heterogeneity in Energy Discrete Choice Experiments: A Review on Methods for Model Selection
Authors: Julian Sagebiel
Published in: Renewable and Sustainable Energy Reviews 69, 94, pp.804–811.
http://dx.doi.org/10.1016/j.rser.2016.11.138
Abstract: Discrete choice experiments are increasingly utilized to inform policy makers in various fields in energy on consumer preferences and willingness to pay values. When translating the results into policy recommendations, it is often difficult for non-experts to understand the underlying implications of different models and associated behavioral assumptions. In this paper, I review proposed methods to compare the two most frequently applied models, the random parameters logit and the latent class logit and investigate the challenges in and implications of model choice for policy makers and practitioners. As an example application, I use data from a discrete choice experiment on private households' preferences for electricity supply quality in Hyderabad, India. The procedures used in the comparative analysis – measures of fit, tests for non-nested models, kernel density estimates of conditional willingness to pay values and choice probabilities – emphasize the difficulties in finding the 'correct' model. The methods presented here can be readily used by other researchers to better understand model performance which ultimately contributes to improving model choice in applied energy research.

Keywords: Choice Model Comparison; Random Parameters Logit; Latent Class Logit; India; Willingness to pay

Chapter 3

Preferences for Electricity Supply Attributes in Emerging Megacities (P2)

Full Title: Preferences for Electricity Supply Attributes in Emerging Megacities – Policy Implications from a Discrete Choice Experiment of Private Households in Hyderabad, India
Authors: Julian Sagebiel and Kai Rommel
Published in: Energy for Sustainable Development 21, pp. 89-99
http://dx.doi.org/10.1016/j.esd.2014.06.002
Abstract: The Indian economy struggles with electricity supply deficits and low quality supply. Although several initiatives including demand side management measures have already been implemented, consumers from different backgrounds suffer from various drawbacks of quality supply. This paper explores the valuation of electricity quality from the perspective of domestic consumers in Hyderabad, India. We conducted a discrete choice experiment with 798 urban households. For analysis, we apply a scale-adjusted latent class model to identify heterogeneity in preferences and in variance-scale. The results confirm the hypothesis of highly heterogeneous household preferences and reveal limited preparedness of domestic users to pay for improved electricity quality and renewable energy. Further, most respondents prefer state owned distribution companies to private enterprises or cooperative societies. We argue that the estimated preferences, implying demand and willingness to pay for single attributes of electricity quality, can help policy makers to adequately incorporate consumers' interests into decision making. The results further indicate that domestic tariff hikes should not be used to finance extension of renewable energies or infrastructure investment to improve reliability in supply.
Keywords: Urban Electricity Supply; Discrete Choice Experiments; Stated Preferences; Scale-Adjusted Latent Class Model; India

Chapter 4

Quality Uncertainty and the Market for Renewable Energy (P3)

Full Title: Quality Uncertainty and the Market for Renewable Energy: Evidence from German Consumers
Authors: Jens Rommel, Julian Sagebiel and Jakob Müller
Published in: Renewable Energy, 94, pp.106–113
http://dx.doi.org/10.1016/j.renene.2016.03.049
Abstract: Consumers can choose from a wide range of electricity supply contracts, including green power options. Electricity produced from renewable energy involves information asymmetries. With a sample of more than 2,000 German electricity consumers, we tested the proposition of a "lemon market" for renewable energy in a discrete choice experiment. Specifically, we found that, compared to investor-owned firms, additional willingness-to-pay for renewable energy is approximately double when offered by cooperatives or municipally-owned electricity utilities. Consumers who are experienced with switching suppliers have an additional willingness-to-pay of one Eurocent per kilowatt hour for cooperatives and two Eurocents for public enterprises. The results demonstrate that organizational transformation in dynamically-changing electricity markets is not only driven by political initiatives but also by consumers' choices on the market. Public policy may reduce information asymmetries by promoting government labeling of green energy products.

Keywords: Cooperatives; Discrete Choice Experiment; Energy Transition; Germany; Willingness-to-Pay

Chapter 5

Are Consumers Willing to Pay more for Electricity from Cooperatives? (P4)

Full Title: Are Consumers Willing to Pay More for Electricity from Cooperatives? Results from an Online Choice Experiment in Germany
Authors: Julian Sagebiel, Jakob Müller and Jens Rommel
Published in: Energy Research & Social Science 2, pp. 90-101
http://dx.doi.org/10.1016/j.erss.2014.04.003

Abstract: With liberalization in 1998, numerous firms have entered the German retail electricity market, including newly formed consumer cooperatives. Based on Transaction Cost Economics, we develop a theoretical framework seeking to explain preferences for electricity supplied by cooperatives from a consumer perspective. Drawing on a convenience sample of 287 German electricity consumers and Choice Experiment data from an online survey, we estimate Willingness-to-Pay values for organizational attributes of electricity suppliers, while accounting for observed and unobserved heterogeneity. Consumers in the sample exhibit a large Willingness-to-Pay for renewable energy. Our results also indicate a substantial Willingness-to-Pay for transparent pricing, participation in decision making, and local suppliers. Democratic decision making – a distinct feature of cooperatives – exhibits positive Willingness-to-Pay values for approximately one fifth of the sample. Taken together, our findings suggest a slightly higher Willingness-to-Pay for electricity produced by cooperatives. Limitations of applied sampling and other important aspects of energy transition are also discussed.
Keywords: Choice Experiments; Cooperatives; Energy transition

Chapter 6

Conclusions

> Some skepticism about the economist's penchant for monetary measurement is no doubt healthy, but it should not be overdone (Freeman III et al., 2014, p.10)

To achieve sustainable electricity supply, the structure and design of electricity markets must be adapted to local contexts. Economies of scale and the resulting natural monopolies in transmission and distribution require market regulation and government intervention. Yet a variety of mechanisms can also allow for privatization and competitive market structures. Consequently, finding the right balance between freedom, competition, and market regulation is a key challenge that policy-makers face.

Electricity is a heterogeneous good that has to fulfill different purposes for a heterogeneous set of stakeholders. In this domain, consumers are an important group because they can shape demand in terms of the attributes of the electricity they use. Unlike in competitive markets, however, electricity consumers are not able to express their preferences through choices, as prices are either zero (e.g., externalities) or fixed. Hence, it is not clear what particular characteristics affect consumer welfare and to what extent consumers are willing to participate in the above-mentioned challenge to attain a sustainable electricity supply. Additionally, conditions on electricity markets differ greatly between emerging and industrialized economies, as do the problems, needs and preferences of consumers, making it difficult to transfer successful transformation strategies between countries. Understanding consumer preferences and how they differ across contexts is, therefore, a difficult yet necessary task for providing advice to policy-makers regarding the design of electricity markets.

This dissertation has addressed the question of how consumer preferences regarding electricity attributes are shaped (*empirical research question*) and how much they resemble each other between (*empirical sub-research questions*) and within (*methodological research question*) contexts. The insights gained here seek to contribute towards finding solutions for

achieving sustainable electricity supply by reducing the knowledge gap regarding consumer preferences and providing methodological foundations for measurement of the value of various electricity attributes which cannot be captured through market observations.

6.1 Results

6.1.1 Contributions of the Individual Papers

To gain a better understanding of differences regarding preferences in fixed contexts (*methodical research question*), **Paper 1** has served as the methodological basis for the subsequent papers, also providing a literature review on methods for discrete choice model selection. The paper focused on models that can incorporate unobserved preference heterogeneity, meaning variation of preferences between people that cannot be explained by observed variables. The results indicate that models chosen by researchers can strongly impact estimated preferences and willingness to pay values. For the Indian case study, preference heterogeneity was best described using three to five distinct latent preference classes, with members within each class having relatively homogeneous preferences. The key contribution of the paper is improved understanding of how unobserved preference heterogeneity can be integrated into analysis while also indicating the importance of including preference heterogeneity in policy recommendations.

Paper 2 took up the findings on preference heterogeneity from Paper 1 and, using a discrete choice experiment to investigate non-marketed characteristics of electricity, analyzed the preferences of private households in the emerging megacity of Hyderabad, India (*empirical sub-research question 1*). The results indicate great unobserved preference heterogeneity between respondents, the majority of whom were not willing to pay for improvements in electricity supply or renewable energy. The policy analysis performed on this data implies that differences in preferences should be incorporated into the design of new policies and tariffs. For example, increasing the share of renewable energy was not perceived as being relevant by about 90% of the respondents, but a subset of respondents was willing to pay a substantial amount for it. Thus, decision makers can make use of this heterogeneity by introducing an optional renewable energy tariff. Even if only a small portion of households were to switch to such a tariff, it could be a viable solution for covering some costs for creating additional renewable energy capacities.

Papers 3 and 4 investigated preferences regarding electricity attributes in the German context (*empirical sub-research question 2*). In contrast to the Indian case, the two discrete choice experiments conducted in Germany focused on the governance structures and locations

of distribution companies. **Paper 3** explored the interaction between the attributes 'share of renewable energy' and 'organizational form of distribution company'. Using discrete choice experiment data from about 2,000 German households, the main finding here was that willingness to pay for electricity from a non-profit oriented company increases when the share of renewable energy is high. This can be said to contribute to our understanding of how preferences are shaped and especially how they shift when the context changes, particularly here how the introduction of renewable energy sources in the electricity mix can shift the importance of the organizational form of an electricity distribution company for consumers.

Paper 4 provided more a more detailed discussion of the findings on electricity cooperatives from paper 3 and sought to investigate what exactly makes energy cooperatives attractive for German consumers. Using a survey with about 300 respondents, a discrete choice experiment was conducted to infer willingness to pay values for distribution company governance attributes, including some attributes typical for cooperatives. It turned out that distribution company location and presence of attributes characterizing cooperatives increased willingness to pay for electricity among German consumers. It was also shown that small details in electricity market regulation, such as price transparency, can make a difference to consumers' willingness to pay.

6.1.2 Key Results and Implications

Taking the individual results together has led to additional insights concerning how preferences are shaped and how they vary between contexts (*empirical research question*). Consumer preferences are complex and taking them into account requires some care, for the following reasons. First, in both case studies, preferences regarding specific electricity attributes did exist, although these differed in magnitude. Consumers in Germany showed a clear willingness to pay for improvements, while willingness to pay values for Indian consumers were, on average, comparatively low.

Second, the hypothesis that preference can vary between consumers within a particular context turned out to be true for both contexts and can be regarded as a general finding that needs to be incorporated into any study of consumer preferences regarding electricity. As **Paper 1** has shown, neglecting this heterogeneity can easily lead to biased estimates regarding preferences and misleading conclusions. For policy recommendations, the findings on preference heterogeneity are at least as important as those on the population-averaged preferences and willingness to pay values. In the presence of preference heterogeneity, policy makers should avoid "one-size-fits-all" policies and provide options for consumers to choose electricity supply as close to their individual preferences as possible. By doing so, policies can hopefully be more effective, targeting those who can receive the highest benefits from

expected changes. Taking the results of the three empirical papers together, for nearly all attributes one-size-fits-all policies are not recommended.

Third, the need to mitigate climate change is differently perceived in Germany and in India. **Papers 3 and 4** indicated great willingness to pay values for renewable energy in Germany. Contrasting this result with **Paper 2**, however, reveals that the great majority of Indian consumers were not willing to pay for renewable energy, which supports the conjecture that people from high-income countries care more about the externalities of electricity production. This finding corresponds with the premises of the theoretical framework I have developed, especially the hierarchy of needs concept (Maslow, 1943), as presented in Chapter 1, which postulates that higher needs – mitigation of climate change, for example – only become relevant after basic needs – here physical electricity access and quality – have been satisfied. This result has important implications for the key challenge to bringing together climate change mitigation and electricity availability: Providing assistance for satisfying basic needs, which includes electricity availability and quality, appears to be a precondition for consumer participation in an energy transition and climate change mitigation. Consequently, policies that promote renewable energy in India need to be designed completely differently than in Germany to find acceptance among the population, as the observation from Germany that people will voluntarily contribute towards renewable energy production cannot be expected in present-day India.

Fourth, the organizational form of electricity distribution companies matters, for Indian as well as for German private households. According to the data, respondents from both countries prefer government-owned companies. Private companies are not the optimal organizational form for distribution companies from a consumer perspective. In Germany, this may be one of the reasons why several municipally-owned distribution companies have successfully entered the market. Moreover, the results from **Paper 3** have revealed that willingness to pay for renewable energy depends on the organizational form of a distribution company. This finding has implications for the design of policies and market restructuring in India as well as other emerging economies: Once competitive retail markets have been established and consumers can choose their distribution company, state-owned companies can still play an important role in facilitating the extension of renewable energy, as the likelihood that consumers will switch to a renewable energy tariff is greater when it is produced by a state-owned company. However, contrasting the results of **Paper 2** with **Paper 4** regarding cooperatives, perceptions and preferences differ between Indian and German consumers. Unlike German respondents, respondents from India did not prefer cooperatives to private companies.

6.2 Limitations

Although the discrete choice experiment results presented here may be useful for informing policy, there are several limitations that need to be considered by researchers and decision makers so as to hinder misunderstandings. Discrete choice experiments have often been criticized for their hypothetical nature, which can lead to 'hypothetical bias'. Several studies have emphasized that, in many cases, willingness to pay from discrete choice experiments is overstated, meaning it is larger than true willingness to pay (Carlsson and Martinsson, 2001; Herriges et al., 2010; Loomis, 2011). Especially when discrete choice experiment results are used to inform policy, it is crucial to make such potential bias explicit. The results presented here are no exception, and is thus likely that the stated willingness to pay values have a larger magnitude than the true ones.

Point estimates derived from statistical analysis in the social sciences strongly depend on theoretical assumptions adopted, model specification, data quality, and sampling strategy. Providing specific recommendations solely on the basis of point estimates of willingness to pay values would thus imply spurious levels of accuracy and would likely be misleading. Therefore, it is not recommended to pin down exact willingness to pay values. Rather, it is more important to understand the direction and magnitude of preferences as well as revealed trade-offs between attributes. Nevertheless, strategies do exist for avoiding this spurious accuracy trap. First, researchers can report lower and upper bounds of willingness to pay and provide ranges in subsequent cost-benefit analyses. Second, if the purpose of discrete choice experiments is to provide recommendations regarding a specific policy, then building stronger links to local conditions and affected people when designing such experiments is likely to provide more accurate results, though this strategy comes at the cost of generality. Third, if exact willingness to pay values for certain attributes are required, a follow-up survey on a smaller scale should then be conducted (Sagebiel et al., 2015).

Another limiting condition is that choices made in stated preference surveys can be subject to the strategic behavior and interactions of consumers. Particularly attributes having public-good characteristics need be interpreted with care, as potential bias due to free-riding possibilities are not addressed in stated preference surveys. Would choices be different if respondents were aware of the choices made by other respondents? Would people free ride if they knew that other people were willing to pay? Such questions cannot be answered with discrete choice experiments, but one could complement the results with game-theoretical concepts and economic experiments to investigate strategic behavior and identify dilemmas of coordination and cooperation (Rommel, 2015). A particular example relevant here is climate change mitigation, which is a public good that, as theory would predict, rational agents are not likely to invest in. Experimental economics has shown, however, that in many

cases people may be willing to voluntarily invest in it, but not to a large enough extent to reach efficiency (Höfer and Rommel, 2015; Zelmer, 2003). For the results presented here, this could imply that willingness to pay is understated and, at least partly, subject to individual rational behavior.

I am aware that the discrete choice experiments presented in this dissertation have captured only a limited number of attributes, so it has not been possible to provide an exhaustive analysis of all relevant electricity attributes. The main reason for this limitation is inherent to the method used. It is usually not advisable to use more than seven attributes per survey, as including more attributes could overburden a respondent's cognitive abilities and may lead to more random choices and higher drop-out rates (Louviere et al., 2006). As a remedy, my co-authors and I have tried to identify the most relevant attributes for private households in extensive pretests, but the necessary neglecting of other attributes should be taken into consideration when using the results for decision-making. For policy makers, it is often helpful to overview preferences for a large number of attributes. Here, meta-studies summarizing preferences for electricity can be a useful tool. In the field of electricity, meta-studies have been conducted regarding preferences for renewable energy production (Ma et al., 2015; Menegaki, 2008; Soon and Ahmad, 2015; Sundt and Rehdanz, 2015), but the literature on the domains of *who, what and where* is not yet sufficiently large enough to conduct meta-studies.

There is evidence that preferences differ by geographical locations (Campbell et al., 2008; Johnston and Ramachandran, 2014; Meyerhoff, 2013; Schaafsma et al., 2013), which can be traced back to socio-economic and landscape-related variables. Further, spatial autocorrelation is likely to exist for willingness to pay values. Incorporating spatial heterogeneity can be important for identifying willingness to pay hot spots, meaning locations where people have very strong preferences regarding certain attributes. For example, in hot areas, people are likely to have greater preferences for avoiding power cuts, because they depend more on cooling devices than people in cooler areas. Spatial aspects of willingness to pay are an important source of preference heterogeneity, and explicit modeling and mapping of spatial willingness to pay can guide policy makers regarding locations where a policy could be most useful or cost-effective. Integrating spatial elements into discrete choice experiments can also help in transferring estimated values to other sites where no primary data collection has taken place. Under the term 'benefit transfer', this approach has become popular in environmental economics (Bateman et al., 2011, 1999; Johnston et al., 2015) but has not yet been applied in the energy sector.

6.3 Policy Recommendations

This dissertation seeks to contribute towards solving the global challenge of achieving sustainable energy provision by bringing together two contrasting aims: mitigating climate change while, at the same time, increasing electricity availability. The policy recommendations presented here have been derived with this goal in mind. In the following, I offer a summary report regarding how the results and insights gained through the research presented here can contribute towards the challenges currently facing policies aimed at achieving sustainable energy.

6.3.1 The Case of India

In India, the ambitious policy goal of achieving full electrification on a low-carbon path is yet to be realized. Currently, the National Action Plan on Climate Change is the most important governmental program for reducing carbon dioxide emissions (Ghosh, 2009). Out of its five missions, two are related to energy: the National Solar Mission and the Mission for Enhanced Energy Efficiency (Harish and Raghavan, 2011). In parallel, the Government of India has taken several steps towards increasing electricity availability and rural electrification, such as under the scheme "Deen Dayal Upadhyaya Gram Jyoti Yojana" for rural electrification (Government of India, 2014). Although rural electrification as well as overall power availability has increased over the last few years, comprehensive access to electricity throughout India is still a major challenge.

Integrate energy policy with other development goals

To achieve a successful energy transition in India, energy policy needs to go hand in hand with appropriate solutions to other developmental challenges, such as reduction of extreme poverty. Thus, in addition to subsidizing renewable energy, the government should invest in policies to enhance development. Moreover, economic growth needs to be more inclusive so that the lower classes can also benefit from it (The World Bank, 2006). Core public services such as health care, education and water supply should be extended to broader layers of the population. Redesigning labor regulations, improving technologies and infrastructure in the agricultural sector, and providing access to markets are all preconditions for energy sector transformation. These suggestions should be addressed in the National Solar Mission, which promotes decentralized investment in solar photovoltaic technologies for private households but which, until now, has only progressed very slowly (Choragudi, 2013; Harish and Raghavan, 2011; Urpelainen and Yoon, 2015).

Reconsider privatization

Preferences regarding the organization of the electricity market in India are quite different to preferences from other countries which have successfully initiated electricity market reforms through privatization. In India, the majority of private households would prefer the state to organize electricity supply, and privatization is regarded as negative. Therefore, any efforts towards privatization should be carefully considered, as they are likely to have limited support from the population. The National Solar Mission supports private players in electricity generation through subsidy payments. But, considering consumer preferences, it would perhaps be more effective if the government directly generates and distributes electricity from solar energy to achieve better acceptance and participation. In this way, policy makers could pave the way for state-owned companies to generate and distribute electricity from renewable sources.

Offer tariff variety

Policy makers should also consider the observation that preferences differ between people and should be reflected in policy design and consumer tariffs. Consumers should be offered a variety of options for voluntarily contributing towards the extension of renewable energy. For example, consumers could have the option of choosing between feed-in tariffs, renewable energy tariffs and dynamic tariffs. A feed-in tariff, such as that implemented in Germany, would provide incentives to private households to invest into decentralized renewable energy production facilities, e.g. rooftop solar photovoltaic panels, thereby guaranteeing households sale of their excess electricity to the grid for a fixed price. A feed-in tariff could be especially attractive for settled residents. In contrast, a renewable energy tariff would give households the possibility to buy electricity from renewable energy sources without investing into privately-owned solar photovoltaic panels. This is a viable option for consumers who want to avoid long-term investments but still want to contribute towards renewable energy expansion. Finally, a dynamic tariff could help to reduce peak loads and increase demand when electricity generation is high, allowing consumers to adapt their consumption to current electricity prices, based on supply and demand, on the generation market and would be especially attractive to higher-income households using multiple appliances. By offering these three options, different consumer groups can contribute, based on their individual preferences and circumstances.

In general, providing more choices to the consumer will likely increase consumer welfare, as individual preferences would be better met. This would facilitate the extension of renewable energy production as more options for participation in the energy transition become

available for consumers. Such options can be incorporated into national-level policies, such as the Electricity Act (see Paper 2), or the National Solar Mission.

6.3.2 The Case of Germany

The German energy transition is already in progress, though new challenges have emerged. Key problems here revolve around how decentralized electricity supply can be organized, how consumers can be integrated into decision making and how the additional costs of generation and distribution can be recovered. Regarding the ambitious aims of the German government to attain a renewable energy generation rate of 80% by 2050 (UBA, 2013a), new ways for promoting electricity from renewable energy sources among private households are needed. A key finding of this dissertation has revealed a large excess of willingness to pay for renewable energy which has not been fully exploited. A reason for this appears to be that the institutional and regulatory setting has not yet been optimized from the consumer perspective (UBA, 2010).

Provide flexibility in retail electricity markets

The introduction of new concepts such as demand-response models, energy-efficient appliances, and decentralized generation require solutions which can allow consumers to make individual choices. Policy makers should thus develop channels for making adoption of these concepts easier for consumers, as only then can efficiency gains from addressing heterogeneity in preferences be captured. Such a development could be set in motion parallel to taking steps for reducing the German Renewable Energy Act apportionment for renewable energy, a one-size-fits-all compulsory tariff for financing renewable energy (Federal Ministry for Economic Affairs and Energy, 2012). An example of including preference heterogeneity would be dynamic tariffs tied to market dynamics, responding to varying levels of electricity production from renewable sources. Even if a large majority may not be interested in such a tariff, some people would be likely to switch to it, thus reducing the demand gap when renewable energy production is low and vice versa. Once such a system has been established and consumers become acquainted with it, these concepts can be mainstreamed on electricity markets.

Consider financing mechanisms

The existence of preference heterogeneity has implications for financing policies. A policy can be financed by lump-sum payments or taxes collected from the whole population, such as the German Renewable Energy Act apportionment, where electricity consumers pay a

top-up for each unit of electricity consumed to finance renewable energy production, or through usage-bound or voluntary payments, such as renewable energy tariffs. If the benefits of a policy are relatively similarly distributed within a population, lump-sum payments can be used. As soon as preference heterogeneity is present, however, policy makers should consider further financing mechanisms based on voluntary payments. In Papers 3 and 4, I have shown that preferences regarding renewable energy strongly vary between German consumers. An advisable strategy here is to use a lump-sum payment to retrieve the minimum required financing for achieving the government's targets for renewable energy generation and, additionally, offer an option for voluntary payments that would finance further extension of the policy.

Promote labeling for renewable energy and make its production more transparent

The research presented here has identified a lack of trust in renewable energy production when supplied by distribution companies. Consumers do seem willing to pay for renewable energy but are hesitant, as they cannot control its quality. At the moment, this trust is being partly regained by cooperatives and municipally-owned distribution companies, but introduction of an accountable label, as has been done for example in the organic food market, could boost trust in the generation process and thus help to increase the overall share of renewable energy.

Decrease market-entry barriers for energy cooperatives

My research has identified additional willingness to pay for attributes which are typically associated with cooperatives. As cooperatives focus in most cases on renewable energy generation, they could be an energy transition facilitator. In this vein, removing market-entry barriers to the retail market for cooperatives may drive consumers towards switching to renewable energy tariffs. The planned reform of the current renewable energy act would substitute the existing feed-in tariff with open competitive bidding for wind energy projects. In theory, such a system should increase market efficiency but would make long-term planning difficult for smaller cooperatives and increase investment risk in them (Bündnis Bürgerenergie, 2016). Open competitive bidding does not take into account that consumers perceive renewable energy differently, depending on who provides it. As indicated in Papers 3 and 4, an important factor for consumers when deciding whether to switch to a renewable energy tariff is how the company that supplies it is organized. In the worst case scenario, small cooperatives that are unable to compete will leave the market and consumer willingness to pay for renewable energy would then likely decrease. Here, policy makers could offer

support for cooperatives so that they would be able to compete with large companies that benefit from economies of scale and have better possibilities for hedging risky investments.

6.4 Outlook: Uses of Discrete Choice Experiments in Energy Policy

In this last section of my dissertation, I will elaborate on the usefulness of discrete choice experiments for decision makers and discuss their various uses in policy contexts. Are discrete choice experiments a meaningful tool for decision makers? What can discrete choice experiments regarding the electricity sector contribute to policy?

Laurans et al. (2013) have identified categories of use within the context of valuation of ecosystem services. I have taken their approach as a basis for examining uses concerning the specific case of electricity and provided examples from the four papers that make up this dissertation. In general, there are three main purposes for discrete choice experiments within policy-making contexts. First, they can be used by decision makers to identify trade-offs between policy options. Second, they can be used to adjust existing policies or regulations. Third, they provide general information regarding public preferences and can be used for long-term policy planning.

Identify trade-offs of policy alternatives: When policy makers are about to implement a new policy or regulation, they need to consider several factors and, under limited budgets, are often forced into trading-off between alternatives. Discrete choice experiments can help to identify the value of these trade-offs by providing costs and benefits for each alternative. For example, Paper 2 has identified the trade-offs between scheduled and unscheduled power cuts. In a policy to reduce power cuts, a policy maker can use such results to decide whether the focus of the policy should be put more on reducing scheduled or unscheduled power cuts. The results of the discrete choice experiment presented here indicate that people in India would prefer a reduction of scheduled power cuts more than of unscheduled power cuts and have implicitly provided a measurable value for this trade off by their estimated willingness to pay values. Such results can be readily integrated into policy-making processes. However, this approach does need to be applied with care, due to the spurious accuracy trap explained in section 6.2

Fine-tune policy: Once a policy is decided upon and about to be implemented, discrete choice experiments can be used for fine-tuning. For example, implementation of the German Renewable Energy Act apportionment for renewable energy could benefit from the results of a discrete choice experiment. Based on the maximum willingness to pay values for

renewable energy, the values of the apportionment could then be adapted. If, for example, the apportionment is below the maximum willingness to pay, then promoting a more rapid extension of renewable energy sources could be considered. In the opposite case, either take steps (e.g., through marketing efforts) could be taken to increase acceptance or effort could be put into finding different financing options for renewable energy.

Support decision making: For many purposes, accurate trade-off values are not required. Rather, policy makers are interested in integrating results into their decision-making process or using them as inputs for discussions. Willingness to pay values can be used as arguments for setting the priorities of a certain policy. For example, Paper 3 suggests that renewable energy share can be more easily increased when channeled through municipally-owned distribution companies or cooperatives than via large private companies. Policy aimed towards increasing renewable energy share can thus make use of such information for supporting market entry for cooperatives, in the expectation that more people will then switch to a renewable energy tariff.

Support marketing and management strategies for distribution companies: Results from discrete choice experiments can also be used by distribution companies, which can then adapt their tariff structures and their products to better meet consumer preferences. Further, they can also use such results for designing internal policies regarding issues such as price transparency. In marketing, such results can help to publicly emphasize company characteristics that are especially valued by consumers. For example, in Paper 4 I concluded that options for customer participation increase their willingness to pay. Consequently, companies may want to discuss opening themselves up to consumer participation in its decision-making process, thereby increasing their attractiveness for new customers.

Verify existing policies: Discrete choice experiment results can be used ex-post, after a policy has been implemented. Especially when a policy has been publicly criticized, such results can be used to reassess the criticism as, in many cases, estimated preferences come from representative surveys and mirror the opinions of relevant segments of the population. As a case in point, the results of Papers 3 and 4, indicating high willingness to pay values for renewable energy, could be used to justify the German Renewable Energy Act apportionment for renewable energy.

Raise awareness of policy makers: In many cases, policy makers do not have a clear picture of consumer preferences, which could result in inaccurate perceptions regarding them. Discrete choice experiment results could raise awareness of policy makers regarding relevant topics. For example, the result from Paper 1 that preference heterogeneity is present in most energy-related topics could help to make policy makers aware that one-size-fits-all policies are likely to lead to acceptance issues.

Evaluate the status quo: Designing new policies is generally based on the assumption that already existing policies are suboptimal. Discrete choice experiments can help to verify or disprove this assumption. For example, the experiment conducted in Paper 2 showed that the majority of respondents in India would like to maintain the status quo of electricity regulation. For a policy maker, this could be taken to mean that policy reform towards privatization is not likely to have much value for private households or that further efforts to create acceptance among the population regarding privatization would be required. It also suggests that arguments in favor of privatization need to be based on other factors than consumer wellbeing.

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Appendix A

Econometric Background of Discrete Choice Experiments

A.1 Economic Model

The dissertation investigates preferences and subsequent demand for goods that are not available on a market. These preferences are similarly shaped as those for marketed goods allowing classical consumer theory to be the foundation of the econometric framework. The main difference to standard theory is that discrete choices rather than continuous choices are to be modeled. When it comes to the choice of a supply company, a consumer only chooses one company and receives his electricity completely from there. All models applied in this dissertation deal with the discrete choice of a consumer. Hanemann et al. (1984) has laid the foundation of demand systems for discrete choice. In general, so he argues, are consumers faced with a two-stage decision process of discrete and continuous choices. First, the consumer decides which good she wants, then how much of it she consumes. Hanemann showed how discrete choices can be modeled consistently to the assumptions of neoclassical preference theory.

In many cases, we are not only interested in the good itself (e.g. distribution company A or distribution company B) but in the characteristics of the good. What is it that makes company A being preferred to company B and what can company B do to change this? In their seminal works, Lancaster (1966) and Rosen (1974) constructed a framework that explicitly models demand as a function of the attributes of a good rather than the good itself. Lancaster uses the example of a bulb. It is not the bulb that the consumer is interested in, it is the light that it gives. And it is also the time when light is required. Utility is hence derived from light at a certain time. More generally, the utility derived from electricity is a

function of its characteristics. These characteristics can either directly affect the consumer, e.g., the frequency of power cuts, or indirectly, like the share of renewable energy or the type of distribution company.

Combining the approaches from Hanemann, Lancaster and Rosen leads to the theoretical model (Alpizar et al., 2003; Louviere et al., 2006) which I used throughout the dissertation. It can be described as follows: an individual i derives utility from the consumption of electricity as well as from a numeraire good z, which is fixed and comes at a price of 1. Electricity is a complex good that is modeled as a contract with a distribution company and, following Lancaster and Rosen, is a function of its characteristics. The contract c is thus $c = f(A)$ where A is a vector of characteristics. Formally the optimization problem is given as

$$Max_c U[\theta_1 c_1(A_1), ..., \theta_N c_N(A_N), z] \tag{A.1}$$

subject to

$$y = \sum_{n=1}^{N} p_i \theta_n c_n(A_n) + z \tag{A.2}$$

$$\theta_n \theta_m = 0, \quad \forall \quad n \neq m \tag{A.3}$$

$$z \geq 0, c_i(A_n) \geq 0 \quad \text{for at least one } n \tag{A.4}$$

where

- U is a quasi concave utility function
- θ is an indicator whether the contract has been bought or not
- n is the index for the different contracts
- $c_n(A_n)$ is a contract with attribute vector A_n
- p_n is the corresponding price of the alternative
- z is the numeraire and y is income (both fixed)

The utility function is assumed to be at least weakly separable so that

$$U = (u(c_1, z), ..., u(c_n, z)) \tag{A.5}$$

Taking into account equations A.3 and A.2 one can derive the indirect utility function V

$$V(A, p, y) = max[u_1(A_1, y - p_1 c_1), ..., u_N(A_N, y - p_N c_N)] \tag{A.6}$$

The indirect utility function gives the highest attainable utility under given prices and income.

From V it follows that a consumer chooses contract m if

$$u_m(A_m, y - p_m c_m) > u_n(A_n, y - p_n c_n) \quad \forall \quad n \neq m \tag{A.7}$$

This theoretical model can be transformed to a random utility model (Manski, 1977; Thurstone, 1927) and utility parameters (i.e. the effect of the characteristics on utility) estimated with discrete choice models such as the conditional logit model (McFadden, 1974). In all papers of the dissertation I applied this framework as the theoretical foundation of choice. The main difference is the specification of c, that is the utility relevant characteristics of the contract.

A.2 Methods to Estimate Demand Functions for Non-Market Goods

In order to measure preferences and demand for non-market goods, several methods exist. The literature distinguishes between revealed and stated preferences. Revealed preferences are useful when transactions on a market can be directly or indirectly observed. For example, the demand for units of electricity can be easily estimated by observing prices and quantities over time. In other circumstances, such data are not available. The demand for better electricity quality is not easily observable. The electricity quality does usually not vary within a region, and there is no market where one can buy electricity quality. Revealed preferences can only be used in a limited way. A popular way to estimate demand for non-market goods is to ask a sample of the population to *state* their preferences. Such hypothetical decisions are contested because it may introduce several biases, yet many researchers consider it as the only way to obtain such data. Two stated preference methods have been frequently applied in the electricity sector: contingent valuation surveys and discrete choice experiments. Both methods are survey-based, and infer willingness to pay values. In contingent valuation, respondents are directly asked to state their willingness to pay, whereas in discrete choice experiments, the researcher asks the respondent to repeatedly choose between different alternatives. These alternatives describe the good by a combination of several characteristics. In this dissertation, the good electricity quality is described for example by the characteristics number of power cuts, share of renewable energy and type of supply company. Discrete choice models then allow to calculate willingness to pay values for each characteristic separately, expanding the informative value of the survey.

A.3 Estimating Utility Functions and Willingness to Pay

Having the theoretical framework – which is valid for all stated and revealed preference methods – fixed, then next step is to derive an econometric model, that can be estimated with available data. In the following, I will briefly outline this derivation for discrete choice experiments. For other revealed and stated preferences methods, the procedure is analogous.

Recall the decision rule from equation A.7. This model is deterministic and assumes that all relevant factors that influence choice are captured. Yet, in practice, we can only observe some characteristics, that led to a choice. To make the model operational, we have to add an unobserved part that captures all effects that have influenced the choice, but that are not observed (by the researcher). It is common to specify the unobserved part as ε_n entering the utility function additively, so that

$$u_m(A_m, y - p_m c_m) + \varepsilon_m > u_n(A_n, y - p_n c_n) + \varepsilon_n \quad \forall \quad n \neq m \tag{A.8}$$

Rearranging leads to

$$\varepsilon_m - \varepsilon_n > u_n(A_n, y - p_n c_n) - u_m(A_m, y - p_m c_m) \quad \forall \quad n \neq m \tag{A.9}$$

Assuming that $\varepsilon_m - \varepsilon_n$ follows a probability distribution, we can write the term in probabilities

Rearranging leads to

$$Prob\{choose\ contract\ m\} = Prob\{\varepsilon_m - \varepsilon_n > u_n(A_n, y - p_n c_n) - u_m(A_m, y - p_m c_m)\} \quad \forall \quad n \neq m \tag{A.10}$$

Assuming that all ε are independently and identically distributed (iid) with a Extreme Value Type I distribution, leads to McFadden's seminal Conditional Logit model (McFadden, 1974) as

$$Pr\{choose\ contract\ m\} = \frac{exp(u_m)}{\sum_{n=1}^{N} exp(u_n)} \tag{A.11}$$

This model can be estimated with the maximum likelihood method and due to its computational simplicity serves as the basis and workhorse for estimation of discrete choice models. As the model is subject several (unrealistic) assumptions, it has been extended, leading to more complex models by relaxing especially the iid assumption to allow for different correlation structures of the error terms. By doing so, it is, for example, possible to model unobserved preference heterogeneity. In the dissertation, I explicitly focused on these models and also investigate the methodical challenges that arise by using such models.