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Studies on energy self-sufficiency in Germany and business models for renewable energies

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“Magnus gubernator et scisso navigat velo et,
si exarmavit, tamen reliquias navigii aptat ad cursum.”
(Epistulae morales ad Lucilium; Lucius Annaeus Seneca)

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Table of content

List of figures

List of tables

Abstract

Embedded in the research fields of energy policy and environmental behavior, this thesis examines drivers, barriers and opportunities of business models for renewable energies and the underlying motivation of municipalities and households striving for energy self-sufficiency. The first of three articles systematically reviews the current state of the emerging field of research on business models for renewable energies, with industrialized and developing countries as the main unit of analysis. The study reveals key differences between developing and industrialized countries: In developing countries, there is a lack of quantitative data; business model opportunities are mainly driven by unfulfilled basic needs or micro-finance; and corruption and weak electricity grids are the main barriers. In industrialized countries, opportunities are driven by climate change mitigation policies and energy efficiency improvements. High costs of energy storage are important barriers and cooperating across industry borders is key in future business models in handling increasing complexity. Based on empirical data, the second article investigates economic, ecological, social and energy system related factors explaining why municipalities strive for energy self-sufficiency with a focus on electricity. The results suggest that environmental awareness, tax revenues, and greater independence from private utilities are positively related to mayors' attitude towards the realization of energy self-sufficiency. In addition, citizens, the political environment, the mayor's political power, and financial resources are key factors for a municipality striving for energy self-sufficiency. Based on empirical data from households, the third article examines the underlying motivational factors that drive private households to purchase renewable energy system components with the purpose of partial energy self-supply. Results show that perceived financial and autarky benefits are the strongest attitudinal predictors of the purchase intention, followed by

environmental awareness and technology affinity. Subjective norm and perceived behavioral control are two additional important predictors of purchase intention. The article contributes to the literature by explaining underlying behavioral factors and linking them to policy recommendations that apply a behavior-policy framework. By proposing a morphological box for energy self-sufficiency, the second and third article are categorized according to their focus within the research on energy self-sufficiency. In sum, the findings of the dissertation help policy makers and industry to set the adequate framework and enable business model opportunities for renewable energies. It also supports them, if desired, to increase the share of renewable energies using the trend towards energy self-supply by precisely addressing motivational factors of municipalities and households striving for energy self-sufficiency.

Kurzfassung (German abstract)

Ziel der vorliegenden Arbeit ist es mögliche Geschäftsmodelle, deren treibende Faktoren, sowie etwaige Hindernisse für die Anwendung erneuerbarer Energien zu untersuchen. Die zentrale Fragestellung lautet, welche Faktoren Haushalte und Gemeinden dazu bewegen, Energieautarkie anzustreben.

Der erste von drei Artikeln gibt einen systematischen Überblick über die derzeit stetig wachsende Literatur im Bereich von Geschäftsmodellen für erneuerbare Energien. Hierbei wird zwischen Entwicklungsländern und industrialisierter Welt differenziert. Die Ergebnisse zeigen in Entwicklungsländern einen Mangel an quantitativer Datengrundlage. Chancen für Geschäftsmodelle ergeben sich hier vor allem durch unerfüllte grundlegende Bedürfnisse und Micro-Finance. Korruption sowie instabile Elektrizitätsnetze sind die größten Hindernisse. In industrialisierten Ländern entwickeln sich neue Geschäftsmodelle aufgrund der Klimapolitik und steigender Energieeffizienz. Dem gegenüber stehen hohe Kosten für Energiespeicherung als zentrales Hindernis. Weitere Geschäftsmodelle ergeben sich durch Kooperationen über Industriegrenzen hinweg, was zunehmend komplexere Geschäftsmodelle ermöglicht.

Basierend auf empirischen Daten untersucht der zweite Artikel ökonomische, ökologische, soziale und auf die Energieversorgung bezogene Faktoren, die erklären, weshalb Gemeinden elektrische Energieautarkie anstreben. Die Ergebnisse zeigen eine Korrelation zwischen Umwelteinstellung, Steuereinnahmen, einer höheren Unabhängigkeit von Energieversorgern und dem Wunsch von Bürgermeistern Energieautarkie zu realisieren. Zudem sind die Meinung der Bürger, das politische Umfeld, der Einfluss des Bürgermeisters, sowie die finanziellen Ressourcen zentrale Faktoren für eine Gemeinde auf dem Weg zur Energieautarkie.

Basierend auf empirischen Daten untersucht der dritte Artikel die Motivation privater Haushalte für den Kauf von Systemkomponenten zur eigenen Energieerzeugung mittels erneuerbarer Energien. Die Ergebnisse zeigen, dass der Wunsch nach mehr Unabhängigkeit und finanziellen Vorteilen die Hauptfaktoren sind, die einen Kauf solcher Systemkomponenten beeinflussen. Dem folgen Umweltbewusstsein und Technologieaffinität. Weiterhin erweisen sich die subjektive Norm und Verhaltenskontrolle als wichtige Kriterien für die Kaufintention. Dieser Artikel trägt zur bestehenden Literatur bei, indem er die zugrundeliegenden Faktoren identifiziert und darauf basierend Handlungsempfehlungen für die Politik gibt. Mit Hilfe eines morphologischen Kastens lassen sich der zweite und dritte Artikel hinsichtlich ihres jeweiligen Fokus kategorisieren.

Die Ergebnisse dieser Dissertation sollen politischen Entscheidungsträgern dabei helfen die richtigen energiepolitischen Rahmenbedingungen zu setzen. Der Industrie können die vorliegenden Ergebnisse weitere mögliche Geschäftsmodelle im Energiesektor aufzeigen. Entscheidungsträger von Gemeinden erhalten Empfehlungen zur Steigerung des Anteils erneuerbarer Energien über den Weg der Energieautarkie für ihre Gemeinden und Privathaushalte.

1 Introduction

Tremendous transformations have already happened within the energy sector; but the fundamental upheaval still lies ahead. Policy makers in most industrialized countries and several developing countries have declared renewable energy generation technologies to be fundamental for their countries' future energy system and to fight climate mitigation. In December 2015, 195 participating countries unanimously agreed to the final global pact, the Paris Agreement, at the 2015 United Nations Climate Change Conference (United Nations, 2015). The members reached the agreement to limit global warming to a maximum of 2 degrees Celsius with an aspiration of 1.5 degrees Celsius via a reduction of carbon output. The outcome has been celebrated as a major breakthrough. This is an enormous challenge and sets ambitious goals for the transition of the energy sector. In Germany, the share of electricity generation based on renewable energies has increased from 10% in 2005 to over 31% at the end of 2015, which makes them the most important source of energy (BMWi, 2016).

The transition of the energy sector is characterized by major changes: from centralized to decentralized energy generation and from a controllable, stable, and predictable to a fluctuating, instable and unpredictable energy generation. Overall, the share of renewable energies is constantly increasing. The scale and impact varies among countries and depends on the extent of the actual transformation of the energy sector and on the type of generation technologies used. These changes lead to new and innovative business models in industrialized and developing countries (Koirala, Koliou, Friege, Hakvoort, & Herder, 2016; Richter, 2013a). Despite enormous progress and investments in the clean tech sector, renewable energy business models still struggle to take off (Richter, 2012). Policy makers and the industry constantly challenge the status quo of energy

policy, questioning how to incentivize market players and how to adjust the regulatory framework to support renewable energies to become economically viable. Therefore, in my first paper, I reviewed the current literature to identify drivers, barriers and opportunities of business models for renewable energies. One opportunity for business models in industrialized countries, in particular in Germany, aroused my interest and shaped the second and third study: The trend towards decentralized energy generation facilitates several municipalities and private households to generate their own energy and to strive for partial energy self-sufficiency, also called 'energy autarky'.

Overall, with a share of 12%, renewables contribute to the generation of primary energy. However, to reach about 100% renewable electricity generation and 80% overall renewable energy generation in the European Union, a long way still lies ahead (European Commission, 2011). To achieve political goals for climate change mitigation, various technical, economical and policy-related questions need to be answered. Three currently vibrant research streams address some of these questions and build the area of research for the three studies of this dissertation: the literature streams on *business models for renewable energies*, on *environmental behavior,* and on *energy self-sufficiency*. Articles two and three also touch on the discussion of concepts for *decentralized energy generation*. The research question of the first article addresses the field of business models for renewable energies. It caught my interest because viable business models are key to the long term success of renewables, thus, the transition of the energy sector. The research questions from my second and third articles are embedded in the streams of environmental behavior and energy self-sufficiency. Energy self-sufficiency in the field of municipalities and also households might be a promising business model opportunity.

1.1 Research questions

In the following, the research questions of each article will be shortly derived and embedded into their field of research, starting with the first article on business models for renewable energies.

A constantly rising number of articles apply business model frameworks to research the current transformation of the energy sector (see chapter 2.1). It is a vibrant field of research, and scholars use the framework in multiple ways. Some discuss the perspective of certain stakeholders (Andersen, Mathews, & Rask, 2009; Christensen, Wells, & Cipcigan, 2012; e.g. Richter, 2013a). For example, Andersen et al. (2009) explain that strong governmental support through tax incentives is a key driver for business models for electric vehicles. Others focus only on certain technologies, such as photovoltaic (PV) (Chang, Hsu, Lin, & Hsiung, 2011; Rai & Sigrin, 2013). In general, scholars apply the concept to better understand driving forces and impeding factors explaining when and how business models in the energy sector become viable. However, current research provides a fragmented picture of the topic. Studies pick specific cases and diverse regions and apply the business model framework heterogeneously. They emphasize varying drivers, barriers, and opportunities they have identified. The questions to be answered in the first article are the following: (1) How do researchers apply the business model concept to the area of renewable energies? (2) Which methodologies and theoretical concepts are applied in connection with research on business models for renewable energies? (3) What are the drivers and barriers for business models for renewable energies, and what are promising opportunities in different regions of the world?

Among the identified opportunities for business models in the area of renewables and sustainability, energy self-sufficiency caught my interest and builds the foundation for the second and third articles of my dissertation. It is based on the trend towards decentralized and local energy

generation and leads to an active role and engagement of consumers. These so called prosumers (producers and consumers at the same time) are no longer passive players in the energy system. Households and municipalities are becoming prosumers by increasingly striving for local energy generation and relative energy self-sufficiency (McKenna, Jäger, & Fichtner, 2014; trend:research, 2013). Schmid et al. (2012) and Müller et al. (2011) discuss the potential of this development in becoming a key pillar of the transformation of the energy system. They conclude that energy self-sufficiency is a strong vision of many regional actors and has economic and ecological advantages, but also additional costs for certain stakeholders. Based on their work, research on energy self-sufficiency (sometimes also called autarkic energy systems or energy autarky) has developed into its own stream of literature. It can be embedded at the intersection of studies on community energy, environmental behavior and research on decentralized energy generation. Energy self-sufficiency can be understood as the capability to cover energy needs using local energy sources. It can be distinguished between relative and absolute energy self-sufficiency. Relative energy self-sufficiency indicates a local energy supply, which does not necessarily require direct self-consumption. The proportion of locally-generated energy to local energy demand defines the *degree of energy self-sufficiency*. In contrast, absolute energy self-sufficiency describes the ability of a region to fully supply itself with its own local energy sources, allowing it to disconnect from the trans-regional energy grid and other energy imports. The overwhelming majority of organizations, regions, municipalities and individuals strives for relative energy self-sufficiency (Abegg, 2011; Kiraly, Pahor, & Kravanja, 2013). Energy self-sufficiency is rather understood as a path to a high amount of locally-generated energy than the desire to disconnect from the nationwide energy supply. This development offers interesting business model opportunities but also several challenges, for example, for the electricity grid.

So far, scholars have described the concept of energy self-sufficiency and studied individual cases from regions or municipalities striving for energy self-sufficiency (McKenna et al., 2014; Müller et al., 2011). Previous research lists advantages based on case studies, such as a decrease in environmental pollution, a rising number of local jobs, a boost in the regional attractiveness, and lower costs for the energy system (Abegg, 2011; Berndes & Hansson, 2007; Müller et al., 2011; Rae & Bradley, 2012; Schmidt et al., 2012). Case studies on municipalities that strive for energy self-sufficiency from Germany, Austria and Switzerland hypothesize a set of underlying drivers, such as local value generation or environmental beliefs (Busch & McCormick, 2014; Fuchs & Hinderer, 2014; Schmuck et al., 2013). However, there is no clear picture of the underlying beliefs or motivational factors that drive decision makers in municipalities. Only by understanding these factors, are policy makers and the industry able to address this trend. Policy makers might support or control this development. The industry can target decision makers specifically and offer suitable concepts. This raises the research question of the second article: Which factors drive municipalities to strive for energy self-sufficiency?

The third paper focuses on households' purchasing behavior of renewable energy system components. On the level of private households, motivations and circumstances differ. By the year 2013, households in Germany primarily invested in photovoltaic on their own rooftop to feed in electricity and receive a guaranteed and predictable return on investment via the German EEG surcharge. Partly because of decreased costs, households have started to purchase certain components of renewable energy systems, such as a storage or photovoltaics, to generate their own energy and become partly self-sufficient. This raises the research questions of the third article: Which factors determine private households' purchasing behavior of renewable energy system

components and how can policy makers and the industry increase residents' intention to invest in these technologies?

1.2 Theoretical foundations and research context

After deriving the research questions of my thesis, this chapter embeds them into their key fields of research. The research questions of this dissertation can be located in three fields of research: research on business models, research on energy self-sufficiency, and research on environmental behavior. The first article involves to research on business models and its application to energy research, on which I will elaborate first.

1.2.1 Research on business models

The scientific community has started to apply the business model concept to the energy sector (Balachandra, Nathan, & Reddy, 2010; Funkhouser, Blackburn, Magee, & Rai, 2015; Jolly, Raven, & Romijn, 2012; Richter, 2013b; Schleicher-Tappeser, 2012).

Being confronted with the terminology business model and broad areas of applications raises the question of a precise definition. The business model concept allows for the analysis of an organization, how it is functioning and how it generates and captures value. In particular, it is valuable to depict changes within business models and their interactions with the outer world. Magrette (2002) describes business models as stories that explain how an organization or business works. Due to Timmers (1998, p. 3) a business model is “an architecture for the product, service and information flows” that includes a description of: (a) “the various business actors and their roles”, (b) “the potential benefits of the various business actors” and (c) “the resources of revenues”. Chesbrough and Rosenbloom (2002, p. 529) define it as “the heuristic logic that connects technical potential with the realization of economic value”. According to Amit and Zott (2001, p. 511) it “depicts the design of transaction content, structure, and governance so as to create value through the exploitation of business opportunities”. In the context of this dissertation, I follow

the definition of Osterwalder (2004), which combines many common definitions very comprehensively: A business model consists of four basic elements: the product, the customer interface, the infrastructure management and the financial aspects. The product describes the area of business and the value proposition the company offers to the market. The customer interface explains which customers are targeted, how the company delivers the product and services, and how the customer relationship looks. The infrastructure, logistical approach, and network a company needs to deliver its value is defined by infrastructure management. The revenue model and cost analysis are addressed within the financial aspects (c.f. Osterwalder 2004). This structure of four basic elements makes up one unit of analysis to examine the literature on business models for renewable energies in the first article.

The successful application of the business model concept in analyzing changing industries has motivated researchers to apply this concept to the energy sector as well. Over the last two decades, research theoretically and practically discussed various aspects and applications of the business model concept in the areas of e-business, innovation, technology and strategy (Amit & Zott, 2001; Prahalad & Hart, 2002; Seelos & Mair, 2007; Thompson & MacMillan, 2010; Zott, Amit, & Massa, 2011). The rise of e-businesses was a revealing application in studying the fundamental changes of a whole industry (Zott et al., 2011). A similar market transformation has started to evolve in the energy sector. Ambitious climate mitigation targets driven from policy makers and societies worldwide have led to intensive support of renewable energy technologies. Their installations and market share have increased over the last decade through market liberalization, subsidies, and extensive research that has led to technological progress. Several new market players have arisen and begun profiting from the market transformation, whereas traditional market players such as utility companies in Germany have struggled (Richter, 2013a).

This market transformation comes with a number of research questions and scholars are trying to understand, describe and forecast future developments that apply to the business model concept. Strupeit and Palm highlight that the change "towards distributed renewable technologies requires not only technological but also organizational innovation in order to engage broad segments of the private consumer market" (Strupeit & Palm, 2016, p. 124). New types of business models are inevitable in making businesses focus on renewables successful (Hellström, Tsvetkova, Gustafsson, & Wikström, 2015). For example, utility companies in the industrialized world are trying to move from an energy provider to a service provider, which is a fundamental change in the business model. Besides studying changes in the business model, the concept also enables scholars to examine drivers, barriers and opportunities and to give policy recommendations to support business models for renewable energies. The first article of this thesis focuses, in particular, on these drivers, barriers and opportunities discussed in the existing literature. In sum, the business model concept is a valuable tool or framework to examine the transformation of an industry such as the energy sector. Zott and Amit (2011, p. 1034) summarize aptly that the "business model can be a vehicle for innovation as well as a subject of innovation". In a still highly-regulated market, policy makers need to set the right stimuli and understand how to support innovative business models.

Following the broad and global view on the current status of research on business models for renewable energies, the field of energy self-sufficiency offers one highly-revealing business model opportunity. Therefore, in the following, I will explain how my second and third article are embedded into this stream of literature.

1.2.2 Research on energy self-sufficiency

Influenced by the system change towards decentralized energy generation and rising environmental awareness, people and municipalities are striving for their own local energy generation in several industrialized countries, which has become a topic of research in recent years. In Germany, a large number of people invest in community energy projects, which have become a relevant part in renewable energy generation. Since 2006 over 718 energy communities have been founded (DGRV, 2014). Also, private households have started to consider certain components of renewable energy systems such as photovoltaic, storage or solar thermal to generate their own energy. In the past, German households considered photovoltaic to be an investment vehicle with a calculated steady return rate. Consequently, all electricity generated was fed into the grid. Khalilpour et al. (2015) calculated that it would be economically viable for households to partially supply themselves with their own electricity generation. Between 2013 and 2015, over 17,000 electricity storage systems have been installed in private German households (Kairies et al., 2015). In the past years, a rising number of municipalities in Germany, Austria and Switzerland have propagated the political goal of local energy independence or energy self-sufficiency, as often referred to (McKenna et al., 2014; McKenna, Herbes, & Fichtner, 2015; trend:research, 2013). Scholars have started to discover this phenomenon and begun to study the trend towards energy self-sufficiency (Hauber & Ruppert-Winkel, 2012; Müller et al., 2011; Rae & Bradley, 2012; Ruppert-Winkel & Hauber, 2014).

The question remains what energy self-sufficiency stands for. This thesis, as most other studies, refers to locally-generated energy that can actually or theoretically cover a certain percentage of energy self-consumption. The concept of energy self-sufficiency has already been studied in a number of publications with very heterogeneous backgrounds or approaches and,

therefore, needs to be clarified. Researchers also refer to energy self-sufficiency with the terms *energy autarky*, *energy autonomy* and *energy self-reliance*, which do not have the exact same meaning (Hauber & Ruppert-Winkel, 2012; Müller et al., 2011; Rae & Bradley, 2012; Ruppert-Winkel & Hauber, 2014; Späth & Rohracher, 2010). Müller et al. (2011) use the term autarky, which is a synonym for self-sufficiency explained by its origin: Autarky, derives from the Greek word 'autárkeia', which refers to 'economic independence or self-sufficiency' according to the New Oxford American Dictionary (2010). In contrast, energy autonomy focuses on the concept of 'self-governance' and 'freedom from external control or influence' (New Oxford American Dictionary, 2010). A wide spectrum of gradations has evolved in practice and in the scientific literature. In general, all related interpretations agree, that to a certain extent, energy is generated locally. Despite this commonality, several dimensions need to be considered to precisely describe the kind of local energy generation. For example: Which kind of energy? On which spatial extent? Relative or physical self-sufficiency? Is the locally-generated energy actually consumed locally or, for example, fed into the grid? Table 1 provides an overview of the most relevant aspects. My second paper focuses on electricity and the spatial extent of municipalities (see Table 1). The third paper sheds the light on both electricity and heat at the household level (see Table 2).

Table 1: *Morphological box to structure the key aspects of energy self-sufficiency and the categorization of the second paper of this dissertation (grey areas mark focus of the second study)*

	Characteristic values			
Type of energy usage	Electricity	Heat	Mobility	
Spatial extent	Household level	Organization- / company level	Municipality level	State-/country
Type of self-sufficiency / strictness of term interpretation	Relative self-sufficiency		Absolute self-sufficiency	
Degree of relative self-sufficiency	Continuum: from 0% to >100% *Defined as the proportion of locally-generated energy to the local energy demand.*			
Degree of self-consumption	Continuum: from 0% to 100%. *Proportion of local energy self-consumption to local generation.*			

Table 2: *Morphological box with the categorization of the third paper of this dissertation (grey areas mark focus of the third study)*

	Characteristic values			
Type of energy usage	Electricity	Heat	Mobility	
Spatial extent	Household level	Organization- / company level	Municipality level	State-/country
Type of self-sufficiency / strictness of term interpretation	Relative self-sufficiency		Absolute self-sufficiency	
Degree of relative self-sufficiency	Continuum: from 0% to >100% *Defined as the proportion of locally-generated energy to the local energy demand.*			
Degree of self-consumption	Continuum: from 0% to 100%. *Proportion of local energy self-consumption to local generation.*			

1.2.3 Research on environmental behavior

The field of research on environmental behavior makes up the second major stream of literature my second and third article relates to. It dates back to discussions, for example, on

recycling behavior or general pro-environmental behavior in the seventies to nineties (Arbuthnot et al., 1976; Grob, 1995; Kaiser, Wölfing, & Fuhrer, 1999). From there on, it has developed into a vibrant field because it is fundamental for climate mitigation policies and business in the areas of sustainability and renewables to understand why, how, and when people pursue pro-environmental behavior.

In the field of research on environmental behavior, scholars apply, test, and propose different theories to explain human behavior in various contexts. Based on the theory of reasoned action, the theory of planned behavior (TPB) has been repeatedly tested and extended in the field of environmental behavior {Ajzen:1991hc, Steg:2009is}. It sets the theoretical basis for the extended models of the second and third article of this thesis. The TPB tries to understand the underlying motivational factors behind thoughts, a behavioral intention, and the resulting behavior. The core of the TPB describes three factors, attitude, subjective norm, and perceived behavioral control, that influence the intention, which itself is a strong predictor of actual behavior. The following examples show the diversity of motivational factors depending on the specific context of pro-environmental behavior and are relevant for the research questions of my second and third paper.

One type of study focuses on electricity saving and energy efficiency behavior in the context of households (Botetzagias, Malesios, & Poulou, 2014; D'Oca, Corgnati, & Buso, 2014; Estiri, 2015; Fornara, Pattitoni, Mura, & Strazzera, 2016; Gadenne, Sharma, Kerr, & Smith, 2011; Scott, Jones, & Webb, 2014; D. Webb, Soutar, Mazzarol, & Saldaris, 2013) or work environment (Dixon, Deline, McComas, Chambliss, & Hoffmann, 2015; Zhang, Wang, & Zhou, 2014). For example, Zhang et al. (2014), in particularly, study attitudinal factors of energy saving behavior in the work environment of Chinese office workers in Beijing; they show that environmental benefit,

organizational benefit, enjoyment, and organizational electricity saving climate are key predictors of attitude and, indirectly, of intention.

A second type of study analyzes general pro-environmental energy generation-related behavior (Huijts, Molin, & van Wee, 2014; Read, Brown, Thorsteinsson, Morgan, & Price, 2013). These studies differ because people do not need to change their individual behavior within their households or at work but are affected rather indirectly within their community. In the case of people opposing or agreeing with wind farm developments, Read et al. (2013) reveal the importance of proximity, visual perception, and sense of place as additional factors to the core theory of planned behavior constructs (attitude, subjective norm, perceived behavioral control). In the case of the acceptance of a hydrogen fuel station, Huijts et al. (2014) present personal norm, affect, perceived technology effects, and trust as the most important predictors of pro-environmental behavior.

A third type of study analyzes peoples' purchasing and adoption behavior of renewable energy generation technologies or green electricity (Leenheer, de Nooij, & Sheikh, 2011; Litvine & Wüstenhagen, 2011; Woersdorfer & Kaus, 2011). For example, Litvine and Wüstenhagen (2011) found that targeted information to increase the perceived benefit of green electricity increases households' green electricity adoption.

Striving for energy self-sufficiency or purchasing renewable energy system components is one type of pro-environmental behavior, which partly relates to energy-saving behavior, general pro-environmental behavior, and purchasing or adoption behavior of renewable energy technologies.

1.3 Research approach and contribution

My dissertation consists of three studies with different methodological research approaches. Research design and methodologies were driven by my research interest and the identified research questions. While the first paper purely reviews and analyzes the existing literature, the second and third papers follow empirical research methods. Despite a clear focus on quantitative methods, I combined them with qualitative approaches. Therefore, my dissertation acknowledges the call for methodological pluralism in research (Onwuegbuzie & Leech, 2005).

My first article systematically reviews the literature on business models for renewable energies. I contribute to the scientific literature by structuring the existing literature by presenting the key drivers, barriers, and opportunities to business models for renewable energies and, finally, by proposing promising avenues for future research. The methodological approach follows the procedures of a systematic literature review suggested by Webster and Watson (2002) and vom Brocke et al. (2009). The scope of this approach is to identify a conceptual framework that helps to depict the field of research and identify white research spots. While developing the conceptual framework, industrialized countries and developing countries turned out to be the core unit of analysis. The analytical process of the review contains five steps: defining the review scope, conceptualizing topics, searching literature, analyzing and synthesizing the literature, and developing a research agenda. The review is characterized by a systematic approach searching the existing literature via keyword search on a pre-defined set of journals.

My second and third articles contribute to the body of literature by answering which underlying factors drive municipalities to strive for energy self-sufficiency and which drive households to purchase renewable energy system components. To the best of my knowledge, both articles are the first of their kind to empirically study these topics. They also contribute to the

literature by extending the theory of planned behavior (TPB), a well-established theory explaining various behaviors, to the fields of electric energy self-sufficiency in municipalities and energy self-sufficiency of households. Both studies are based on the methodological approach of Fishbein and Ajzen (2010). Self-collected data from surveys is analyzed based on a pre-developed research model. In a first step, qualitative and structured expert interviews, in particular among the targeted research population, are conducted to identify a set of underlying beliefs that influence a person's behavior. In combination with variables from the existing literature and based on established categories, hypotheses and the final research model are formulated. After a pre-study to test the survey items, the main studies are conducted. In the second article of this dissertation, I have gathered 109 fully-completed surveys online or via telephone mainly from mayors in Germany. Mayors are a busy and difficult to reach research population, which makes the conducted primary data set very valuable. For the third article, I have gathered 395 surveys from household owners in Germany. Finally, the collected survey data is used to test the main research model in each article. In the third article, I have combined the methodological approach of Fishbein and Ajzen (2010) with a policy framework of Steg and Vlek (2009) and an additional round of expert interviews to draw policy recommendations and to assess the findings.

1.4 Dissertation outline

Table 3 provides an overview of this dissertation showing the objectives, scientific methodology, and theoretical approach of each study. The remainder of this dissertation is structured as follows. Chapter 2 presents the first paper of the dissertation “Comparing drivers, barriers, and opportunities of business models for renewable energies: A review”. This article has been accepted for publication by the journal of *Renewable and Sustainable Energy Reviews* in December 2015. Chapter 3 contains the second research article with the title “Transforming the energy system: Why municipalities strive for energy self-sufficiency”. It has been accepted for publication by the journal of *Energy Policy* in August 2016. Chapter 4 comprises the third research article “Revolutionizing the energy system: Why citizens strive for energy self-sufficiency”, which is submitted for publication. To conclude, I briefly summarize this dissertation with the main theoretical and practical contributions, limitations, and future research (chapter 5). References to the research articles can be found at the end of each chapter, respectively.

Table 3: *Overview of this dissertation*

	General introduction		
	Article 1 Global level: Drivers, barriers and opportunities	*Article 2* Municipality level: Striving for electric energy self-sufficiency	*Article 3* Household level: Purchasing renewable energy system components
Study objectives	Categorizing the literature on business models for renewable energies based on several units of analysis; Understanding the systematic and key differences between business models for renewable energies in industrialized versus developing countries Analyzing and discussing drivers, barriers and business model opportunities; Identifying white research spots based on a research framework	Understanding the underlying motivation of municipalities striving for energy self-sufficiency Providing policy recommendations on how municipalities could be supported Proposing a morphological box to structure different aspects of energy self-sufficiency and to categorize the present study	Understanding households' desire for their own energy supply by studying their purchasing behavior of renewable energy system components Providing one comprehensive model that explains households' behavior in the context of renewable energy self-supply independent from the technology necessary to achieve it Understanding households' willingness to pay a premium for renewable energy self-supply Linking behavioral factors to accurate energy policy interventions
Scientific methodology	Systematic literature review	Qualitative-empirical (Survey: N = 19) and quantitative-empirical (Survey: N=109)	Quantitative-empirical (Survey: N = 395) and expert interviews
Theoretical approach	Business model theory	Theory of planned behavior, theory of reasoned action	Theory of planned behavior, theory of reasoned action, behavior-policy framework
	General conclusion		

1.5 References

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2 Comparing drivers, barriers, and opportunities of business model for renewable energies: A review

Journal publication and conference publication:

- Journal publication:

  Engelken, M., Römer, B., Drescher, M., Welpe, I., Picot, A. (2016). Comparing drivers, barriers, and opportunities of business models for renewable energies: A review. *Renewable and Sustainable Energy Reviews*, 60, 795-809. doi: 1.1016/j.rser.2015.12.163. [Impact Factor: 5.9]

- Conference publication:

  Engelken, M., Römer, B. (2014, December). *Exploring business models for renewable energies - a literature review*. Presented at the Energy Systems Conference 2014, London.

Keywords: Renewable energy; business model; country comparison; driver; barrier; opportunity

Abstract

This article systematically reviews the emerging field of research on business models for renewable energies, differentiating between developing and industrialized countries. The key findings on developing countries are as follows: first, there is a lack of quantitative data; second, opportunities are driven primarily by unfulfilled basic needs and micro-finance, whereas corruption and weak electricity grids are the main barriers; and third, business models should be replicable. The key findings on industrialized countries are as follows: first, opportunities are driven primarily by climate change mitigation and energy efficiency improvements; second, stuck thought patterns and high costs of energy storage are important barriers; and third, cooperation is a key in future business models to handle increasing complexity. This review reveals implications for researchers and policy-makers. Promising avenues for future research are the analysis of intermodal business models and opportunities concerning energy self-supply and renewable district heating. Policy-makers are advised to design legal frameworks that account for the global nature of the renewable energy challenge and are simultaneously adapted to regional disparities.

3 Transforming the energy system: Why municipalities strive for energy self-sufficiency

Journal publication:

Engelken, M., Römer, B., Drescher, M., Welpe, I. (2016). Transforming the energy system: Why municipalities strive for energy self-suffiency. *Energy Policy*, 98, 365–377.

doi: 1.1016/j.enpol.2016.07.049. [Impact Factor: 2.6]

Keywords: Energy self-sufficiency; municipality; theory of planned behavior; regional development; renewable energy

Abstract

Despite evidence that a rising number of municipalities in Germany are striving for energy self-sufficiency, there is little understanding of the driving factors behind this development. We investigate economic, ecological, social and energy system related factors that drive municipalities to strive for energy self-sufficiency with a focus on electricity supply. The empirical data for this study is based on insights generated through expert interviews (N = 19) with mayors, energy experts and scientists as well as a quantitative study among mayors and energy officers (N = 109) of German municipalities. Results show that environmental awareness, tax revenues and greater independence from private utilities are positively related to the mayors' attitude towards the realization of energy self-sufficiency. Furthermore, citizens, the political environment, the mayor's political power, and his/her financial resources are relevant factors for a municipality striving for energy self-sufficiency. Policymakers need to decide whether or not to support mayors in this development. For suitable policy interventions, the results suggest the importance of an integrated approach that considers a combination of identified factors. Finally, we propose a morphological box to structure different aspects of energy self-sufficiency and categorize the present study.

4 Revolutionizing the energy system: Why citizens strive for energy self-sufficiency

Current status:

Engelken, M., Römer, B., Drescher, M., Welpe, I. (2016). Revolutionizing the energy system: Why citizens strive for energy self-supply. (working paper, submitted for publication).

Keywords: Energy self-sufficiency; households; citizens; theory of planned behavior; renewable energy

Abstract

In the past, households in Germany widely invested in renewable energy technologies (mostly photovoltaic) to receive guaranteed return rates based on extensive subsidies. These feed-in tariffs have been tremendously reduced and, consequently, households' behavioral motivations have changed: They have started to adopt various technologies to supply themselves with energy. In this study we investigate the underlying motivational factors that drive private households to purchase renewable energy system components with the purpose of partial energy self-supply. The study's data is comprised of qualitative interviews (N = 20) and a subsequent quantitative survey (N = 395) among household owners from Germany. By studying households' purchasing intentions, we found perceived financial and autarky benefits are the most relevant attitudinal predictors, followed by environmental awareness and technology affinity. Subjective norm and perceived behavioral control are important predictors of purchase intention. Policy makers and the industry could further promote this development with tailored information strategies that address, in particular, perceived autarky, financial benefits and subjective norms. We suggest support schemes for renewable energy systems to address perceived behavioral control factors. These schemes include necessary ongoing subsidies and a reliable regulatory and financial policy framework. This article contributes theoretically and practically to the environmental behavior and policy literature: It explains underlying behavioral factors and links them to policy recommendations by applying a behavior-policy framework.

4.1 Introduction

Private households account for about thirty percent of total energy consumption in Germany (German Environment Agency, 2015). Understanding and influencing their environmental behavior allows policy makers to achieve ambitious goals for the expansion of renewable energies (Baake, 2015). In particular, households' aspiration for partial energy self-supply offers a promising additional pillar for the transition of the energy system.

To understand consumers' environmental behavior, researchers study all kinds of behavioral aspects for diverse renewable energy technologies. This allows one to describe consumers' behavior, explain behavioral changes and recommend suitable interventions for policy makers and marketers of renewable energy system components. In this line, scholars have studied the purchasing behavior of photovoltaic (PV) systems (Korcaj, Hahnel, & Spada, 2015), solar thermal systems (Woesdorfer and Kaus 2011), renewable heating systems (Bjørnstad, 2012; Michelsen & Madlener, 2013), microgeneration technologies (Alam et al., 2014; Goto & Ariu, 2009; Leenheer, de Nooij, & Sheikh, 2011), green electricity (Litvine & Wüstenhagen, 2011) and electricity storage systems (Kairies et al., 2015; Römer, Reichhart, & Picot, 2015). However, current literature presents a heterogeneous picture of pro-environmental purchasing behavior of private households. For example, Leenheer et al. (2011) identifies environmental concerns, technology affinity and reputation of electricity companies as the most important drivers for Dutch households generating their own power via microgeneration technologies (e.g. micro-CHP). Financial factors and power outages did not have a significant effect. In contrast, for a German sample Korcaj et al. (Korcaj, Engel, & Spada, 2014) reveal that the aspiration of financial gains, autarky benefits and social status have a positive relationship to the attitude towards purchasing PV systems.

Not only does the current literature provide inconclusive results for understanding households' aspiration to purchase renewable energy system components but also market surroundings have changed in recent years: Feed-in tariffs for solar PV dropped significantly to about 13 cents/kWh for small-scale installations, while household electricity prices increased to around 25 cents/kWh. Thus, it can be beneficial to consume a certain percentage of one's own self-produced electricity instead of buying all of it from the grid. Considering total costs, renewable energy technologies for private households have become economically feasible or they are closer to economic viability than a few years ago (Khalilpour & Vassallo, 2015). Up to now, in Germany, solar PV was an investment vehicle with guaranteed payback for the vast majority of customers, which is currently changing: Not just innovators and early adopters but also average consumers start to consider using diverse renewable energy system components to supply themselves with their own energy. With a different behavioral purpose, also a different set of drivers should explain households' behavior.

The heterogeneous picture together with the changing market surroundings lead to the following research questions: Which factors determine private households' purchasing behavior of renewable energy system components for self-supply? How can industry and policy makers address underlying motivational factors to influence households' purchase intentions?

The focus of this study is households' intention to purchase any kind of technology able to generate or store renewable energy with the purpose to be partially self-sufficient. To study the drivers of private households striving for partial energy self-supply this study applies a multistep approach based on Fishbein and Ajzen (2010) and links it to the policy framework of Steg and Vlek (2009). We conducted 20 semi-structured qualitative interviews among household owners and deduced the theoretical model. In the quantitative main study, 395 households from Germany

participated. Finally, we linked the identified underlying drivers to potential policy interventions. This approach provides a comprehensive analysis of the underlying drivers and aggregation of potential policy interventions to foster the transition of the energy system via households.

The key findings of this study are: Private households purchase renewable energy system components and strive for partial energy self-supply for a set of reasons. Perceived financial benefits, perceived autarky benefits, their environmental awareness and technology affinity are positively related to households' attitude towards the purchasing of renewable energy system components; in addition to attitude, households' social environment and perceived behavioral control (PBC) are positively related to intention towards the purchasing behavior. We suggest the following interventions: Attitudinal and subjective norm factors should be addressed via tailored information campaigns, a type of informational strategy. They should particularly focus on perceived autarky benefits and environmental awareness. Additionally, even though policy makers would like to reduce them, technology specific subsidies are the most effective intervention to address PBC. This study contributes to the literature on pro-environmental behavior, energy autarky and decentralized energy systems in a theoretical and practical way: It extends the theory of planned behavior (TPB) and applies it to households' purchasing behavior. It identifies key drivers of households purchasing renewable energy system components at a point of time in which people in Germany seriously start to consider generating their own energy for the first time. By linking identified drivers to suitable interventions, this study derives practical implications for policy makers and the industry of energy products addressing private households.

The remainder of this study is organized as follows: Section 4.2 addresses the conceptual and theoretical background. Section 4.3 presents the methodological approach. Section 4.4 and 4.5

describe the results of the study and discuss its implications for theory and practice. Finally, section 4.6 concludes with the contribution and aggregates the policy recommendations.

4.2 Conceptual model and theoretical background

We apply the TPB from Ajzen (1991) as an underlying theory in combination with the pro-environmental behavior policy framework from Steg and Vlek (2009). First, we examine private households to understand the motivational factors of their purchasing of renewable energy system components. Second, we derive and present policy recommendations by linking these factors to corresponding intervention options.

4.2.1 Theory of planned behavior

Applying the TPB model helps to grasp the volitional and non-volitional thoughts and decisions behind any type of individual behavior. The major advantage of this framework as a theoretical foundation in the context of environmental behavior is its "ability to consider a large set of complex determinants in a relatively simple framework" (Litvine & Wüstenhagen, 2011, p. 463). The TPB has been successfully applied in various fields of environmental behavior research to study individual behavior, such as purchasing green electricity (Litvine & Wüstenhagen, 2011), recycling (Cheung, Chan, & Wong, 1999; Nigbur, Lyons, & Uzzell, 2010), monitoring electricity consumption (T. L. Webb, Benn, & Chang, 2014), electricity saving and the energy efficiency behavior of households (Botetzagias, Malesios, & Poulou, 2014; D'Oca, Corgnati, & Buso, 2014; Estiri, 2015; Fornara, Pattitoni, Mura, & Strazzera, 2016; Gadenne, Sharma, Kerr, & Smith, 2011; Scott, Jones, & Webb, 2014; D. Webb, Soutar, Mazzarol, & Saldaris, 2013), and saving electricity at work (Dixon, Deline, McComas, Chambliss, & Hoffmann, 2015; Zhang, Wang, & Zhou, 2014).

To investigate the antecedents, the TPB requires one to define the studied behavior. With the purpose of supplying oneself with energy, we specify the behavior as *purchasing renewable energy system components for private households within the upcoming three to five years*, which

is a reasoned action in the sense of the TPB. We underlined and reminded survey participants of this behavior definition on each page of the questionnaire to ensure a clear understanding of the context. *Renewable energy system components* comprise any kind of renewable energy technologies or products that are suitable for private households to supply themselves with energy. This includes the generation or transformation as well as the storage of electricity and heat. Examples are photovoltaic, solar thermal, pellet heating, geothermal systems, and electricity storage systems. All these products are components of a system to supply households with their own energy.

According to the TPB, the three predictors *attitude, subjective norm* and *perceived behavioral control* (*PBC*) determine the behavioral intention, which itself has shown to be an accurate predictor of actual behavior (Ajzen, 1991). In a study of Armitage and Corner (2001), the TPB explains 39 % and 27 % of the variance in intention and behavior, respectively, and they report high correlations between behavior intention and actual behavior ranging from .47 to .53. Applying the TPB to the context of this study, *attitude* aggregates all beliefs and influences that explain the degree of a household to be in favor or to endorse the behavior of purchasing renewable energy system components. *Subjective norm* comprises the overall perceived influence and pressure a household's owner feels from his or her social environment to act and decide accordingly. *PBC*, the third predictor of intention, reflects the degree to which a household perceives to be able or incapable of performing the actual behavior.

4.2.2 Conceptual model

This study focuses on understanding the underlying factors of households' purchasing behavior and connecting these factors to corresponding interventions suitable to encourage households' pro-environmental behavior. The pro-environmental behavior policy framework of Steg and Vlek (2009) builds the overall framework of this study. It links environmental behavior research to corresponding interventions within four steps: first, determining the type of behavior; second, understanding the factors relevant to the behavior; third, choosing corresponding interventions; and finally evaluating their effectiveness.

To understand the factors of the relevant behavior (second step), Steg and Vlek (2009) suggest the TPB as a suitable theory to study environmental behavior, which can be classified as focused on 'gain goal-frames' within the goal-framing theory (Lindenberg & Steg, 2007). The purchasing behavior of renewable energy products can be understood as a gain or benefit oriented type of behavior. Due to reality constraints, we follow the established procedure of the TBP and measure *intention* as an indicator of future behavior. The proposed and tested research model of this study is based on the core TPB variables *attitude, subjective* norm and *PBC* with a particular focus on the antecedents of attitude. We derived these antecedents in a two-step approach. First, we base them on the antecedents identified by Korcaj et al. (2015). Second, following the established methodological approach of the TPB, we conducted 20 semi-structured interviews with the targeted research population. This helped to validate, refuse and supplement variables to our proposed model. Due to the nature of the TPB, all antecedents are considered perceived and not objective attributes of households' attitudinal beliefs. Based on these analyses, we are able to present the key drivers and to discuss the corresponding policy and business interventions. In the

following, we build on the results of the interviews and literature research and present the hypotheses underlying the proposed research model.

4.2.3 Hypotheses

Applying the core model of the TPB based on Fishbein and Ajzen (2010) to households' purchasing intention, it can be hypothesized:

> *(H1) The attitude towards purchasing renewable energy system components, (H2) subjective norm, and (H3) PBC are positively related to the intention to purchase these systems following within three to five years.*

Several studies have shown the influence and importance of environmental awareness, also referred to as environmental concern for intention, mediated by attitude towards pro-environmental behavior (De Groot & Steg, 2007; Do Valle, Rebelo, Reis, & Menezez, 2005; Gadenne, Kennedy, & McKeiver, 2008). Environmental awareness describes people's concerns about the negative consequences of humans and their own behavior on the environment. In other words, a high environmental awareness expresses advantages for the community, as described by Korcaj et al. (2015). These people worry about the human-environment relationship and express a high degree of environmental awareness through their attitude, intention and eventually their concrete actions such as recycling. Groot and Steg (2007) have shown the mediated influence of environmental concern via attitude on pro-environmental behavior. Renewable energy system components are mainly perceived as environmental-friendly technologies. By purchasing these systems, people supply themselves with sustainable energy, they are aware of their reduced negative impact on the

environment and they express a very concrete pro-environmental behavior. Therefore, based on previous research and as a result of our expert interviews, the following can be hypothesized:

H4: Environmental awareness is positively related to the attitude towards purchasing renewable energy system components.

At an individual level, a number of perceived benefits form one major precursor of people's attitude to perform a certain behavior (Kim, Mirusmonov, & Lee, 2010; Park & Ohm, 2014). Perceived financial benefits are one specific type of individual benefit that is particularly relevant for major investments such as heating systems. They describe the perception of a relative financial advantage – profit or savings – of a purchase or investment decision compared to other options. For instance, in Germany, feed-in tariffs have guaranteed the financial attractiveness of solar PV installations for grid feed-in as an investment option with a fairly predictable profit. In contrast, supplying oneself with energy might save a decent amount of money. Still, a few years ago, a study from the Netherlands focusing on drivers of generating and consuming their own energy via micro-CHP concluded that financial benefits are irrelevant (Leenheer et al., 2011). However, prices for renewable energy technologies have dropped, meanwhile, and adjusted subsidies incentivize electricity storage systems in Germany, for example. A more recent study from Australia by Khalilpour et al. (2015) calculated that it would be economically beneficial for households to supply themselves with electricity to a certain degree while still maintaining a grid connection. Therefore, based on Korcaj et al. (2015) and due to changed market and policy conditions, the following can be hypothesized:

H5: Perceived financial benefits are positively related to the attitude towards purchasing renewable energy system components.

Generating one's own energy gives households the perception of being more independent from conventional energy sources, rising energy prices and utility companies, even though they normally still keep and need a grid connection. A number of conceptual studies discusses these advantages and refer to it under the concept of energy autarky, energy self-sufficiency, or energy self-reliance (Menegaki, 2008; Müller, Stämpfli, Dold, & Hammer, 2011; Rae & Bradley, 2012; T. S. Schmidt, Blum, & Sryantoro Wakeling, 2013). This independence expresses a perceived benefit for households and, therefore, it can be hypothesized that:

H6: Perceived autarky benefits are positively related to the attitude towards purchasing renewable energy system components.

Perceived costs comprise monetary costs, non-monetary efforts and risks related to renewable energy system components. These can be potential maintenance costs, replacement costs or risks of failure. Korcaj et al. (2015) showed the negative relationship between perceived overall costs of PV and the attitude towards purchasing PV systems. Therefore, it can be hypothesized that:

H7: Perceived overall costs are negatively related to the attitude towards purchasing renewable energy system components.

Affinity towards a technology expressed a household's general attitude and open-mindedness towards technologies. For instance, early adopters show high levels of technology affinity. Leenheer et al. (2011) showed this relationship in the energy sector: Households' technology affinity is positively related to their purchase intentions of CHP systems. Following previous literature and according to the TPB framework, all underlying beliefs and antecedents are mediated by attitude, subjective norm or PBC (Ajzen, 1991; 2002b). Therefore, we hypothesize that technology affinity can be an antecedent of attitude, thus:

H8: Technology affinity is positively related to the attitude towards purchasing renewable energy system components.

4.3 Study method and data

4.3.1 Methodological approach

Based on the well-established multistage approaches of Venkatesh and Davis (2000) and Fishbein and Ajzen (2010), we followed three main steps to develop the survey and gather the necessary data. First, we conducted twenty qualitative semi-structured interviews to identify and verify potential variables in addition to those we derived from the literature. Following the Fishbein and Ajzen, this step includes precisely defining the behavior, specifying the research population, formulating the items for the pilot questionnaire, conducting the pilot questionnaire and analyzing the results to filter the most mentioned factors. Second, we conducted a pre-study to test the questionnaire with the derived items with another eighteen participants. This helped to clarify certain items and to enhance the overall understanding and quality of the questionnaire. In the third and final step, the main study was carried out by a professional research agency via an online survey in December 2015. The procedure was as follows: Participants received an email with the link to the survey. Since participants only came from Germany, all materials and questions were presented in German. After the first page with a short explanation of the survey context, participants went through two filter pages with screen-out questions. These questions ensure that participants are only homeowners of houses or apartments who can make decisions about the investment and the installation of a heating system and also of a PV system. In addition, survey participants were asked whether they have ever heard or read about certain renewable energy system components relevant for private households. Anyone who was not a house owner or who had never heard anything about renewable energy system components for private households was screened-out.

4.3.2 Data & Sample

The final sample for the main analysis consists of N = 395 valid participants who are homeowners between the age of 25 to 75 years old (5.1 % female respondents), and who can make decisions about their energy systems and investments. In total, 749 participants clicked on the invitation link, 191 had been screened-out, and 69 did not complete the survey, which results in 489 completed samples. To ensure a high quality of the sample, we screened out another 94 participants based on a so-called trap question (‘Please select the item strongly disagree’) in the last part of the survey, which results in a final valid sample of N = 395 participants relevant for the statistical analysis. Using a trap question as a single quality measure is a transparent, clear and therefore very good procedure to eliminate click-through and any other kind of dubious or doubtful survey participants. The demographic data shows the broad variety of the sample (see Table 4): Participants come from all over Germany, have diverse educational backgrounds, persons per household range from one to over five, and diverse income levels are covered. 4% have a monthly available household income (after tax) up to 1,000 €, 29 % up to 2,500 €, 56 % up to 5,000 €, and 11 % more than 5,000 €.

Table 4: *Demographic data of survey participants*

Items	Parameter	N	%
Gender	Male	197	49.9
	Female	198	5.1
Age	20-29	8	2.0
	30-39	67	17.0
	40-49	115	29.1
	50-59	140	35.4
	60-69	55	13.9
	Over 70	10	2.5
Education	Secondary school	90	22.7
	High school	49	12.4
	Completed apprenticeship	108	27.3
	University degree	141	35.7
	PhD	7	1.8
	1 person	35	8.9
Persons per household	2 persons	150	38.0
	3 persons	104	26.3
	4 persons	80	2.3
	5 or more	26	6.6

4.3.3 Measurement & Data Quality

All measurements from this study are based on items validated in previous studies. Items are measured with a 7-point Likert scale (from 1 – *strongly disagree* to 7 – *strongly agree*) or in the case of willingness-to-pay (WTP) a premium (1 – *very unlikely* to 7 – *very likely*) (Likert, 1932). Variable items have been displayed fully randomized and measure participants' perceptions or beliefs. Final constructs, items and the underlying literature are shown in Table 8. The path analysis was examined using AMOS for SPSS 23.

The reliability and validity of the measured constructs are evaluated with the computed values of Cronbach's alpha, composite reliability, factor loadings and average variance extracted

(AVE) and meet the recommended criteria (see Table 5). All Cronbach's alpha values exceed the threshold of .70 and most exceed even .80 (Bernstein & Nunnally, 1994; Cronbach, 1951; Porter & Donthu, 2008). Measures of composite reliability exceed .80 for all constructs (Bagozzi & Yi, 1988). To ensure convergent validity, all factor loadings surpass the recommended value of .70 (Anderson & Gerbing, 1988; Chin, 1998; Porter & Donthu, 2008). All values for AVE exceed the generally applied value of .50 (Bhattacherjee & Premkumar, 2004; Fornell & Larcker, 1981; Gray & Meister, 2004). Furthermore, Fornell and Larcker (1981) recommend an additional criterion to test for discriminant validity: The AVE must be greater than the squared correlation between any two constructs, which is the case in this study, and, therefore, the required level for discriminant validity is met.

The quality of the research model is evaluated via the model fit criteria that show a good fit for the path analysis: GFI = .984 (recommended level > .9); SRMR = .027 (recommended < .08); RMSEA = .057 (recommended: < .06); χ^2/df = 2.28 (recommended: < 3).

Table 5: *Internal reliability and convergent validity of the measurement model*

Construct	Item	Internal reliability	Convergent validity		
		Cronbach's alpha	Factor loadings	Composite reliability	Average variance extracted
Intention	INT1	.80	.92	.91	.84
	INT2		.91		
Attitude	ATT1	.83	.92	.92	.85
	ATT2		.92		
Social norm	SN1	.77	.91	.90	.81
	SN2		.89		
Perceived behavioral control (PBC)	PBC1	.81	.93	.91	.84
	PBC2		.90		
Environmental awareness	ENV1	.93	.93	.96	.88
	ENV2		.95		
	ENV3		.94		
Perceived financial benefits	FB1	.81	.83	.89	.73
	FB2		.87		
	FB3		.85		
Perceived autarky benefits	AUT1	.86	.79	.90	.66
	AUT2		.84		
	AUT3		.82		
	AUT4		.86		
	AUT5		.73		
Perceived costs	COS1	.72	.73	.84	.64
	COS2		.86		
	COS3		.80		
Technology affinity	AFF1	.79	.79	.88	.71
	AFF2		.85		
	AFF3		.88		

4.4 Results

4.4.1 Descriptive statistics

The results show high values of intention and, particularly, attitude towards purchasing renewable energy system components. On a scale from 1 (*very low*) to 7 (*very high*), 32.1 % of all participants show a high (6) or very high (7) purchase intention (M = 4.9; SD = 1.5). 65.4 % of the survey participants indicate a high (6) or very high (7) attitude (M = 5.9; SD =1.1). Purchase intention and PBC (M = 5.0; SD = 1.54) have the highest variances of all variables.

4.4.2 Hypothesis testing

The results support all hypotheses except for hypothesis seven. The TPB constructs attitude (H1, β = .250, p < .001), subjective norm (H2, β = .317, p < .001) and PBC (H3, β = .226, p < .001) have a significant positive relationship with intention to purchase renewable energy system components. At 44 %, these three variables explain a large portion of the variance of intention (R^2 = .44). In addition, environmental awareness (H4, β = .167, p < .001), perceived financial benefits (H5, β = .355, p < .001), perceived autarky benefits (H6, β = .278, p < .001) and technology affinity (H8, β = .102, p < .05) are significantly and positively related with attitude. The results do not support hypothesis seven (perceived overall costs on attitude) (H7, β = -.037, p < .279). Altogether, 64 % (R^2 = .64) of the variance of attitude is explained. All results are illustrated in Figure 1.

Potential additional influences of four control variables, gender, age, education and income have been tested. None of them had a significant effect except for age; participants' age is negatively, weakly related to purchase intention.

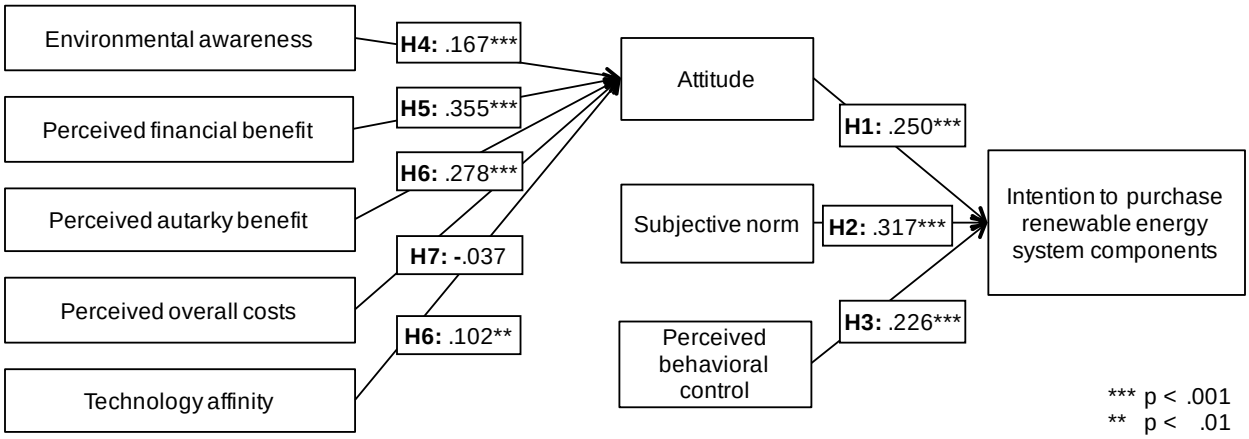

Figure 1: Extended model of households' purchasing intention of renewable energy system components.

4.4.3 Relative importance analysis for the predictors of attitude

The relative importance analysis based on Johnson and LeBreton (2004) allows us to precisely weigh the influence of the antecedents of attitude. Thereby, relative importance „refers to the contribution a variable makes on the prediction of a criterion variable by itself and in combination with other predictor variables" (Tonidandel & LeBreton, 2011, p. 2). The analysis is a helpful supplement to multiple regression, which has been applied in the literature numerous times because it reveals additional and different information. It is designed to calculate the relative importance in the case of correlated predictor variables and it can be interpreted as a measure of relative effect size. Transforming the predictors into orthogonal variables, then calculating the regression and using the resulting standardized regression coefficients eliminates the effect of multicollinearity. The results show that perceived financial benefits and perceived autarky benefits are relatively the most important predictors of attitude. They are almost equally important at 31% and 29% without a statistical significant difference. Still very relevant but relatively less important are the effect sizes of environmental awareness (18%) and technology affinity (17%). Their

difference in relative importance is statistically significant from autarky and financial benefits, but not among each other. Even though perceived overall costs are not significant in the model, it is necessary to include this predictor in the analysis; the effect is calculated with 5% based on the survey data (see Table 6).

Table 6: *Relative importance analysis of key predictors of attitude*

Variable	Relative importance
Financial benefits	31 %
Perc. autarky benefits	29 %
Environmental awareness	18 %
Technology affinity	17 %
Perceived overall costs	5 %

4.5 Discussion and implications of results

In the following, we discuss the results of the proposed and tested model predicting households' purchasing intention of renewable energy system components (second step of the policy framework) and link them to suitable policy interventions (third step of the policy framework). We complement the discussion of the quantitative results by having a closer look at two components of PBC and the willingness to pay a premium for energy self-supply. Based on the results of the quantitative main study, we conducted three expert interviews with industry and politics to reflect the results and receive additional practical input concerning the range of potential implications.

4.5.1 Drivers of households' purchasing intention

Our results indicate that the proposed model is reasonably supported by the empirical data. With an explained variance of 44 % of the variable intention and 64 % of the variable attitude, our model is a promising approach to explaining households' purchase intention of renewable energy system components. The results indicate that the purchase intention is strongly predicted by a combination of factors. First, the findings suggest the TPB as a suitable underlying theoretical framework to predict households' purchasing intention of renewable energy system components. Results show that attitude, subjective norm and PBC build three strong and important predictors of households' purchasing intention. Second, the results suggest that the four factors perceived financial benefits, perceived autarky benefits, environmental awareness, and technology affinity are major predictors of attitude.

On average, households had a relatively high purchase intention, but also a high variance from no intention at all to a very high intention. Other studies report a lower purchasing intention

(e.g. Korcaj et al., 2015), which might have various reasons: Whereas others focused on a certain type of technology, we asked rather broadly for all kind of renewable energy system components. Compared to a few years ago, purchase intention might have increased due to higher financial attractiveness (Khalilpour & Vassallo, 2015), general awareness and perceived autarky benefits.

Perceived financial benefits seem to be the most important driver of attitude towards the purchasing behavior, which is an opposing result compared to Leenheer et al. (2011). They studied households' intention to generate their own power via micro-CHP in the Netherlands in the year 2010 and found environmental concern to be the key factor behind this behavior, which supports the argument that people's attitudinal beliefs have changed meanwhile. First, certain renewable technologies have actually become economically feasible, both by themselves and because of subsidies. Second, people also perceive these technologies to be financially beneficial. For instance, a monitoring report about electricity storage systems highlights that over 80% of surveyed households invested in storage systems to protect themselves against rising energy prices (Kairies et al., 2015). This driver is a financial one but also an argument for independence, the second key driver in our study.

The relative importance analysis shows that *perceived autarky benefits* are almost equally important to households as financial benefits. Whereas financial benefits are a rational and conspicuous factor for most people, autarky benefits are rather subjective and intangible. Being able to partially supply oneself with one's own energy can be seen as a value per se that gives households additional freedom and independence such as possessing one's own car. Partial energy self-sufficiency fulfills households' desire to be more independent from the state, their utility provider, conventional energy sources and rising energy prices (Korcaj et al., 2015; Müller et al., 2011; Rae & Bradley, 2012; Römer et al., 2015; J. Schmidt et al., 2012). Since people, for example,

in Germany tend to dislike their utility providers (Richter, 2012), supplying oneself with energy even becomes a way of satisfaction against those companies. Perceived autarky benefits offer a promising motivational factor beyond pure economic considerations. Policy makers and the industry could successfully address it to market renewable energy products to households.

Environmental awareness and *technology affinity* are the third and fourth almost equally important predictors of attitude. They are still very relevant but relatively less important compared to financial and autarky benefits. Environmental awareness is a factor characterized by benefits for society and in the long run. It is driven by personal values and norms. Considering investments of several thousands of euros for renewable energy system components, such a factor is likely to be less relevant for the average consumer compared to other factors. In the literature, environmental behavior appears to be the most relevant predictor of pro-environmental behavior if the studied behavior is comparably easy to realize or for a specific customer group (Leenheer et al., 2011; Onwezen, Antonides, & Bartels, 2013). The relationship between attitude and the factor technology affinity could be explained by the product life cycle. Despite all the attention, households partially supplying themselves with energy is still a niche market. Consequently, technologically adept people are more likely to spend time on these technologies.

Surprisingly, *perceived overall costs* did not have a significant negative relationship with attitude, which could be for various reasons. There is no generally valid negative relationship between perceived overall costs and attitude that can be found in the literature but a more differentiated and context-specific view of costs and risks. Some studies differentiate between costs and risks, others don’t; some studies found perceived risks or perceived costs to be a predictor of attitude, whereas others found it to be a direct predictor of intention (Alam et al., 2014; Korcaj et al., 2015; M. C. Lee, 2009; Park & Ohm, 2014; Wu & Wang, 2005). We follow the logic of the

TPB and argue that only the three factors attitude, subjective norm and PBC determine intention and that these factors aggregate a number of additional factors we want to explain. Perceived costs might have become less relevant as a predictor of attitude compared to a couple of years ago when other surveys had been conducted. Reasons could be increased product quality, experience and trust. The results could also be understood in the way that costs are not a predictor of attitude; they might come into play as a predictor or moderator of the actual purchasing behavior, which we could not evaluate due to reality constraints. Another explanation might be the variable itself; based on other studies, our variable aggregates costs and risks, which might be too generic.

Subjective norm is the strongest predictor of intention in our model, which underlines the importance of role models and the positive influence of neighbors, friends and the community. A positive experience of others with technologies for energy self-supply is likely to influence one's own purchase intention positively. The high relevance of this factor emphasizes its importance as one clear basis for policy recommendations.

PBC is the third key, direct predictor of purchase intention: households that perceive to have the control or possibility to purchase renewable energy products are likely to have also a high purchase intention. The results of our qualitative semi-structured upfront interviews suggested, above all, the relevance of financial and technological aspects for PBC in the context of this study. Renewable energy technologies demand for relatively high upfront investments in comparison to running costs. Thus, it can be assumed that the financial abilities of households in particular are likely to be a major antecedent of PBC.

In addition to the three core variables of the TPB, control variable *age* had a negative and statistically significant relationship with intention. This relationship has been shown before (Leenheer et al., 2011) and is not surprising because naturally elderly people are less willing to

invest in their own energy supply systems that can have a pay-back time of up to 20 years apart from a generally lower technology affinity.

4.5.2 Willingness to pay a premium

As an additional parameter, we asked for the willingness to pay a premium of 10% (WTP a premium) and the appropriateness of a price premium of 10% for renewable energy system components. WTP is a commonly used measure in research to get a feeling about people's economical assessment of a product or service - for instance, about the WTP a premium for green electricity (Litvine & Wüstenhagen, 2011). Even though these two variables are not included in our theoretical prediction model, we think they provide a better understanding of households' behavioral considerations and offer avenues for further discussion and future research.

To assess the WTP a premium, participants were asked: "Would you be willing to invest in a renewable energy generation or storage system (e.g. PV, solar thermal or electricity storage) if you knew that this system was 10% more expensive compared to conventional electricity or heating supply via your utility?" 25% answered with a high or very high likelihood to pay such a premium and the majority (56%) was indifferent or slightly pro or contra. To evaluate the appropriateness of a price premium, households were asked how they perceive a price premium of 10%: "not a lot", "in between" or "a lot". On a scale from 1 (*not a lot*) to 7 (*a lot*), 21% of surveyed households perceived 10% premium as a lot (6 or 7), whereas 15% perceived it as not a lot (1 or 2). Figure 2 and Figure 3 provide an overview of the results.

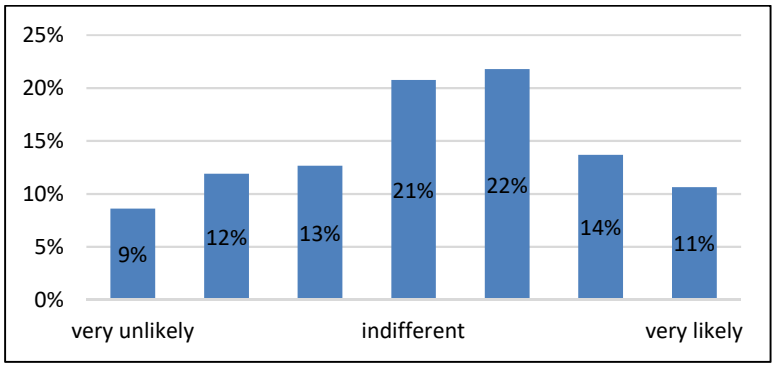

Figure 2: WTP a premium of 10%

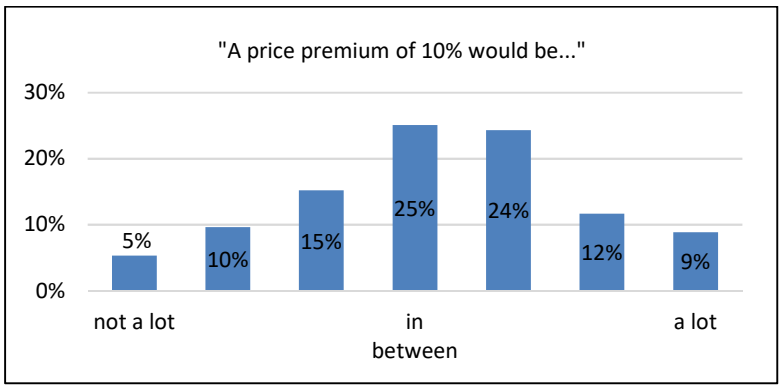

Figure 3: Appropriateness of a price premium of 10%

Overall, 24% of the survey participants indicating a high or very high WTP a premium of 10% shows that not only pure financial aspects are relevant, despite the fact that perceived financial benefits are the most important predictor of attitude. What seems to be contradictory actually isn't: On average, a combination of factors influences people's purchase intention. For example, people value autarky benefits and environmental awareness, which might motivate them to pay a premium. The evaluation of *WTP a premium of 10%* reveals valuable insights that need to be treated with caution, however. Certainly, this WTP a premium applies only to specific customer groups and the

strength of the link to actual purchasing behavior might vary. Expressed via the diffusion of innovation theory framework, probably innovators and early adopters are primarily among those customers that are willing to pay a premium. Within this framework, innovators and early adopters account for 16% of all customers; the early majority would be the next innovation step and comprises another 34% of the customers (Rogers, 1995). Overall, renewable energy systems for energy self-supply of private households are definitely still within a very early market phase in Germany and in other countries. For example, between 2013 and 2015, about 17,000 electricity storage systems that store electricity primarily from PV systems have been sold to private German households, which is still a small amount compared to 40 million households in Germany (Kairies et al., 2015).

4.5.3 Policy and market interventions

After understanding the underlying factors of households' purchase intention, the question needs to be answered, which interventions that support this pro-environmental behavior are to be made. A theoretical framework from prior research and expert interviews link the tested model to policy recommendations. Our recommendations for politics and industry to motivate households to purchase renewable energy products are based on two strategies: It is necessary to combine *informational strategies* addressing motivational factors and *structural strategies* addressing contextual factors.

Our model reveals six core factors to be relevant and addressed that can be split into motivational and contextual factors and, thus, into the corresponding strategies derived from the policy framework of Steg and Vlek (2009) and outlined in Table 7. Motivational factors refer to a person's perspective and his or her attitudes. Contextual factors are externally driven and refer to

the circumstances a behavioral decision is made under. Nevertheless, both types of factors might also affect each other. If a person does not have the opportunity – the PBC – to behave pro-environmentally, for example, by recycling, a positive attitude towards recycling wouldn't be sufficient. All attitudinal factors are considered primarily as motivational factors. These are perceived autarky benefits, financial benefits, environmental awareness and technology affinity. Subjective norm can be understood as both a motivational and a contextual factor, whereas PBC is a pure contextual factor.

Two types of informational strategies are suitable to change prevalent motivations, perceptions, cognitions and norms. First, "persuasion via tailored information" addresses perceived autarky benefits and environmental awareness. Due to an overall high awareness and positive attitude towards renewable energies in Germany, general and broad information strategies are less likely to influence purchase intentions significantly. Tailored information to households with high perceptions of autarky benefits, awareness of financial benefits, high WTP and high environmental awareness are promising types of intervention to trigger a behavioral change. We recommend focusing especially on autarky benefits, since it is not only a relatively important factor but also a factor of potentially high intangible value. Autarky benefits comprise self-sufficiency itself, a higher independence from utilities or energy providers and a perceived "insurance" against rising energy prices. Even though these factors cannot be translated into a concrete WTP, a high correlation (.42) between our measured WTP a premium of 10% and perceived autarky benefits suggest that technology providers might be able to convince these households to pay a premium by emphasizing autarky benefits.

In response to the subjective norm as an important factor of our model, "social support and role models" have proven to be very useful types of interventions (Abrahamse, Steg, Vlek, &

Rothengatter, 2005; Schultz, Nolan, Cialdini, Goldstein, & Griskevicius, 2007; Steg & Vlek, 2009). By locally providing information about other citizens investing successfully in renewable energy products, a city or region is able to trigger households to follow these role models. Role models, tangible and concrete examples create a better understanding, an easily accessible source of information and awareness for advantages of households' own energy supply. For example, several participants reported that the campaigns and information provided by the green party in Germany positively influenced their knowledge about other projects and technological possibilities. In addition, interviewed industry experts highlight word of mouth for investment decisions in renewable energy system components. Marketers in the energy sector might address peers via viral marketing campaigns, social networks and bring-a-friend recommendation mechanisms. In addition, local or nationwide awards, projects and clusters supporting and communicating successful renewable energy projects positively affect subjective norms. Examples from Germany are '100 percent renewable energy regions' or 'bioenergy village' (BMEL, 2014; IDE, 2014).

Motivating households to undertake major investments in their own energy supply should also be triggered by structural strategies. They function by changing circumstances and increasing the attractiveness of renewable energy products compared to conventional solutions; in other words, they reward good or punish bad behavior. Structural strategies apply in two situations: If high financial investments or major behavioral changes need to be stimulated or if circumstances impede a desired behavior. Both is the case for purchasing renewable energy products. PBC beliefs are strongly related to households' financial capabilities, which need to be addressed with structural strategies. We suggest linking perceived financial benefits, an attitudinal factor, and financial control beliefs in respect to policy recommendations. Our results affirm PBC having a significant

positive impact on households' purchasing intension of renewable energy products. This has relevant practical implications and suggests two types of interventions: certain types of subsidies or regulatory policies. The latter either enforce the installation of particular technologies, for example, for new buildings or policies that make alternatives more expensive. A regulatory policy is, for example, the case for smart meters in Germany – new buildings have to install a smart meter. However, technologies for energy self-supply need to be tailored to a specific building and they do not fit to all kinds of buildings. Thus, these kinds of policies could be precarious. Therefore, in line with our expert interview partners, we suggest sticking with policies that support and subsidize certain technologies and pro-environmental behavior. An additional important factor for the industry is predictability of the regulatory framework. The challenge for policy makers is to slightly adjust the policies in response to new technological developments without destroying the basis for the planning of companies that have just adapted to the current situation.

Overall, a combination of structural strategies and informational strategies are necessary to motivate more households to invest in renewable energy products in order to supply themselves with renewable energy. The strategies can be summarized as follows: first, policy makers and the industry need to make renewable energy products appealing and communicate them to address autarky benefits, environmental awareness and subjective norm. Second, despite necessary policies reducing subsidies, they need to make it financially feasible to address financial aspects.

Table 7: *Application of the policy framework and results of households' renewable energy purchasing model*

	Step	Description	Households' renewable energy purchasing model
(I)	Type of behavior	Determining the type of behavior that should be changed to improve environmental quality	Households' purchasing behavior of renewable energy system components
(II)	Factors of relevant behavior	Understanding the underlying factors of the relevant behavior	• Perceived financial benefits • Perceived autarky benefits • Environmental awareness • Technology affinity • Subjective norm • Perceived behavioral control
(III)	Interventions	Choose corresponding and best fitting interventions to encourage pro-environmental behavior	*(A) Informational strategies:* • Persuasion via tailored information to address autarky benefits and financial benefits • Social support & role models to address subjective norm factors and environmental awareness *(B) Structural strategies:* "reward good and punish bad" • Tailored subsidies and/or potential legal regulations to address financial benefits and PBC • Long guaranties to address PBC • Reliable planning horizon
(IV)	Effectiveness of interventions	Evaluate the effectiveness of the interventions chosen	Via ongoing monitoring during policy implementation

4.5.4 Limitations and future research

The survey data of the main study is based on a panel of a professional research agency. Even though this is common practice in research, there might be a certain self-selection among participants because research agencies do not recruit randomly. However, they come from all over Germany, rural as well as urban areas, have diverse educational backgrounds and vary concerning their household income. All participants are household owners that have the power to make

decisions about investments into their own energy supply systems and, therefore, they are a very valuable target research group.

This study focuses on the factors determining purchase intention and links it to promising policy interventions. Due to reality constraints, we cannot measure actual behavior nor can we evaluate the actual effect of certain policy interventions on households' behavior. Additionally, perception of the identified factors is likely to be different in other countries not least because of diverse policy conditions. However, our study method is well established and still allows one to describe the status quo, extend the theoretical framework and draw concrete conclusions for policy makers and the industry. Therefore, we are confident we have provided valuable insights for researchers and practitioners.

WTP should be seen as an indicator that needs to be treated with caution: Even though this variable is used often, there is a relevant difference between what people answer to such a question and how people actually behave when it is time to suit action to the word.

Our study offers several links for future research. First, fellow researchers should test the effects of suggested interventions on households' perception or on their behavior. Second, the importance of particularly perceived autarky benefits could be translated into an accurate figure for willingness to pay a premium for different customer groups. Some approaches can be found in the literature (Burkhalter, Kaenzig, & Wüstenhagen, 2009; Mattes, 2012). Third, future research could direct its attention towards landlords' behavior and the question how to make them invest in renewable local energy generation and storage technologies. With regard to the antecedents of attitude, future research might separate perceived costs and risk and test the proposed model. Lastly, researchers should address the fundamental question of whether or not and to which extent households should be motivated to supply themselves with energy.

4.6 Conclusion

This paper enhances the understanding of private households striving for partial energy self-supply. The goal of this study was twofold: First, testing a proposed model predicting households' purchase intention of renewable energy system components to understand the underlying behavioral factors. Second, deducing suitable interventions from these factors to further support this development. These interventions build a set of recommendations for policy makers and the industry. Furthermore, we contribute to the body of literature by extending the TPB model to the case of purchasing behavior of any kind of renewable energy system components for households.

We find strong support for our model that was tested against empirical data collected from 395 household owners in Germany. Our study suggests that households' motivation to purchase renewable energy system components is a combination of very different underlying factors. Attitude towards the purchasing behavior, subjective norm and PBC are the three key direct predictors of purchase intention. Additionally, our findings show that elderly people are less likely to make such an investment. Attitude itself can be predicted via four key factors: perceived financial benefits, perceived autarky benefits, environmental awareness and technology affinity. Financial benefits and autarky benefits are both equally important and relatively more important than the last two.

To improve people's attitude, we suggest that policy makers and the industry apply informational strategies and provide tailored information to address the four predictors of attitude. Particularly perceived autarky benefits and environmental awareness offer the change to communicate additional value from energy products beyond pure financial benefits.

People's social environment forms the second strong leverage to increase purchase intention because it has shown to be a notable predictor of intention in this context. Both, industry

and policy makers can address subjective norms by highlighting adoption rates and role models of own-energy generation, an additional type of information strategy.

Investments in one's own energy generation systems are generally expensive and, therefore, structural strategies are necessary if wide behavior changes are aspired and should be triggered. Tailored subsidies will be inevitable for the upcoming years to promote certain technologies such as storage systems. However, based on consistent expert views, we recommend that policy makers do their best to create reliable and predictable framework conditions that create long-term investment security. In addition to subsidizing renewable energy system components, regulatory requirements for certain levels of self-consumption need to be clarified.

Finally, policy makers and researchers should evaluate, discuss and decide whether and to what extent they want to play an active role in this development and how costs and benefits are distributed. Households could become a key pillar within the energy transition by partly generating their own renewable energy but still staying connected to the electricity grid, which also seems to be attractive from an economical perspective (Khalilpour & Vassallo, 2015).

4.7 Appendix: Additional materials and analyses

Table 8: *Constructs and items of the main survey*

Construct		Items	Based on
Intention	INT1	I intend to purchase renewable energy generation or storage systems for my household within the upcoming 3-5 years.	Fishbein and Ajzen (2010), Webb et al. (2014)
	INT2	I would like to purchase renewable energy generation or storage systems for my household within the upcoming 3-5 years.	
Attitude	ATT1	I find RE generation and storage systems for households are reasonable.	Ajzen (2002), Fishbein and Ajzen (2010), Zhang et al. (2014)
	ATT2	I consider RE generation and storage systems for households to be a good idea.	
Subjective norm	SN1	Most people (friends, family, colleagues) who are important to me would approve my purchasing RE systems for my household.	Ajzen (2002), Fishbein and Ajzen (2010), Zhang et al. (2014)
	SN2	Most people whose opinions I value think that it is reasonable to purchase RE systems for private households.	
Perceived behavioral control (PBC)	PBC1	For me purchasing RE systems for my household is under my control.	Fishbein and Ajzen (2010), Webb et al. (2014), Zhang et al. (2014)
	PBC2	If I really want I can purchase RE systems for my household.	
Environmental awareness	ENV1	I am concerned about the environment.	Bang et al. (2000), Römer et al. (2014)
	ENV2	I am concerned about environmental pollution.	
	ENV3	I am concerned about water and air pollution.	
Perceived financial benefits	FB1	I find RE systems for my household serves as a financial provision for old age.	Korcaj et al. (2015), Park et al. (2014), Scott et al. (2014)
	FB2	I find RE systems for my household is a secure financial investment.	
	FB3	I find that purchasing a RE system for my household is a profitable investment in the long run.	

Table 9: *Constructs and items of the main survey (continued)*

Construct		Items	Based on
Perceived autarky benefits	AUT1	I find I can compensate for rising energy prices with a RE generation or storage system.	Korcaj et al. (2015), Römer et al. (2014)
	AUT2	I find a RE system allows me to secure part of my energy provision.	
	AUT3	I find a RE system gives me more control over my energy provision.	
	AUT4	I find a RE system enables me to become independent of energy providers.	
	AUT5	For me it is important to be self-sufficient concerning my energy provision.	
Perceived overall costs	COS1	I find the costs attached to RE systems for households too high compared to the benefits.	Dany and Römer (2014), Korcaj et al. (2015), Park et al. (2014)
	COS2	I find that RE systems for my household result in high effort and costs for me.	
	COS3	I think that purchasing and maintaining a RE system for my private household is associated with too high costs.	
Technology affinity	AFF1	I like trying out and using new technologies.	Dany and Römer (2014), Gagnon et al. (2012)
	AFF2	I am interested in renewable energy technologies and follow respective news.	
	AFF3	I see myself as open to new technologies (e.g. technologies in general and renewable energy technologies in particular).	

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5 Conclusion

The goal of my dissertation was to support policy makers, the industry, and researchers with their aim of transforming the energy system towards a decentralized renewable energy generation. Therefore, I shed light on drivers, barriers, and opportunities for renewable energy business models and, in particular, on energy self-sufficiency, as one promising business model opportunity, and tendency in some industrialized countries. As Müller et al. (2011, p. 5802) describe, "decentralization increases producers' and consumers' freedom regarding their technological choice and opens up opportunities for local innovations." In the following conclusion, first, I will summarize the findings of the papers, second, elaborate on the main contributions, third, describe implications for future research, and, finally, provide an overview of general implications for the policy maker.

5.1 Summary of findings

The first article (chapter 2) categorizes the literature on business models for renewable energies and analyzes drivers, barriers, and business model opportunities. The distinction of scientific studies, with a focus on developing countries and those with a focus on industrialized countries, builds the main unit of analysis. In combination with additional units of analysis (type of renewable energy, energy usage, empirical and non-empirical methodologies, business model theory, business model opportunities, barriers, and drivers for business models) it was possible to draw a clear picture of the work from previous studies and discover avenues for future research.

For developing countries, a lack of quantitative, statistical, and economic data has resulted in mainly qualitative, case study-based research on business models for renewable energies. Possible explanations are that the necessary data is not provided by local institutions and that mostly foreign researchers lack the financial resources and access to gather sufficient amounts of empirical or statistical data from developing countries. Hence, fellow researchers should find innovative ways to collect empirical data, which would allow them to apply additional scientific methodologies. The discussed business model opportunities in developing countries are driven by unfulfilled basic needs and micro-finance targeting the bottom of the pyramid. Products and services are specially designed for customers at the lower end of the economic pyramid, fulfilling their everyday needs, as, for example, described by Bocken et al. (2014) and Mahama (2012). Corruption and weak electricity grids are among the most named barriers for business models in the developing world (Da Silva, Buchholz, & Furtado, 2012; Harish, Raghavan, Kandlikar, & Shrimali, 2013; T. S. Schmidt, Blum, & Sryantoro Wakeling, 2013). Lastly, in contrast to those in industrialized countries, business models need to be simple to replicate to become successful and relevant.

In industrialized countries, very different patterns and commonalities appeared: The main drivers for business models for renewable energies are climate change mitigation and energy efficiency improvements. Overtime, decreasing costs of certain technologies, such as solar PV, arose as an additional driver, as described by Schleicher-Tappeser (2012). On the opposite side, stuck thought patterns and high costs of energy storage proved to be key barriers that need to be addressed (Lih, Yen, Shieh, & Liao, 2012; Richter, 2013a). In general, rather complex business models, such as community energy based on biofuel or geothermal, are discussed for industrialized countries. A major opportunity arises from cooperation as a key in future business models in handling this increasing complexity.

Out of several business model opportunities for renewable energies, one aspect in particular aroused my interest: Municipalities and households striving for energy self-sufficiency have a potentially high relevance and impact on the transition of the energy system. Key questions within this field of research remained unanswered. The first key question is: Which factors drive municipalities to strive for energy self-sufficiency? The findings depict a multi-layered picture of the underlying motivational belief structure of decision makers within municipalities. Interestingly, these factors, based on the belief structure, vary among municipalities (paper two, chapter 3) and single households (paper three, chapter 4). This variation has been identified based on the results of qualitative pre-studies conducted among the targeted study participants and tested in the main studies. In the context of municipalities, I investigated economic, ecological, social, and energy system-related factors and focused on self-sufficiency of the electricity supply. The results of the hypothesis testing confirm the application of the theory of planned behavior to energy self-sufficiency in municipalities. Results show that environmental awareness, tax revenues, and greater independence from private utilities are positively related to mayors' attitude towards the realization

of energy self-sufficiency. Furthermore, mayors' beliefs of what citizens and the close political environment, such as other mayors, think are positively related to subjective norm. Finally, financial resources and political power are strong antecedents of perceived behavioral control. Thus, these factors are relevant for municipalities striving for energy self-sufficiency. Despite indications of previous studies, the costs of realizing energy self-sufficiency did not have a significant negative relationship with the intention of realizing it. Previous studies have shown the relationship between costs and intention to follow a certain behavior in other coherences (Dany & Römer, 2014; De Groot & Steg, 2007; Luarn & Lin, 2005; Wu & Wang, 2005). Interviewees reported relatively low costs for the municipality itself for realizing energy self-sufficiency. The municipality does not necessarily invest its own money but sets the framework for the energy policy, which might explain the result. Interestingly and unexpectedly, the data does not support the hypothesis that creating jobs is a driver for energy self-sufficiency. This could be explained by the fact that a job effect rather occurs on a federal state or national level than on the municipality level.

In the context of households (paper three, chapter 4), the motivational factors slightly vary. The goal was to understand household's aspiration to purchase renewable energy system components for self-supply. This refers to all types of renewable technologies and systems that enable a household to partly or fully supply itself with renewable energies. The results show that perceived financial and autarky benefits are the two most relevant attitudinal predictors, followed by environmental awareness and technology affinity. Besides these attitudinal predictors, subjective norm and perceived behavioral control are significant and important direct predictors of purchase intention. The results demonstrate two aspects: First, the purchasing behavior can only be explained by a combination of factors. Second, contrary to the results of Leenheer et al. (2011),

today, perceived financial benefits seem to be one of the most important (but not stand-alone) drivers of attitude towards purchasing behavior. This could be explained by technological progress and cost reductions, which make renewable energy technologies attractive for an increasing number of people (Khalilpour & Vassallo, 2015). In contrast to today, a couple of years ago, only a minority of innovators or idealists was willing to invest in its own energy supply.

5.2 Main contributions of the dissertation

This dissertation is embedded in the broad research fields of *(renewable) energy policy* and *environmental psychology*. In particular, within these fields of research, it contributes to the body of knowledge of and literature on *business models for renewable energies*, *energy self-sufficiency*, (*pro-)environmental behavior* in the following ways: first, by suggesting a research framework for business models for renewable energies; second, by explaining the underlying drivers of the trend towards energy self-sufficiency in the context of municipalities and private households; and third, by providing recommendations to policy makers and the industry on how to stimulate municipalities' and households' desire for their own energy supply based on local and renewable energy sources.

The suggested research framework structures the selected literature on business models for renewable energies. It clarifies the current state of the literature and highlights white spots in the research field for fellow researchers in the field of energy policy and related business models. The main distinction between industrialized and developing countries allows for a better understanding of local disparities and global commonalities. The categories energy, methodology, and business model are applied and complement the research framework. These categories comprise additional units of analysis. The first key outcome of the analysis is a call for a more properly applied business model theory that allows for a better comparison of research studies. The second key outcome is the disclosure of commonly applied theories fellow researchers could connect to, such as organizational learning, open innovation approaches, or the concept of the bottom of the pyramid. The third key outcome is the disclosure of repeatedly suggested policy recommendations from research on business models for renewable energies to address barriers and support opportunities.

By answering the question of why municipalities strive for energy self-sufficiency, the second paper contributes to the literature on energy self-sufficiency and (pro-)environmental behavior by extending the theory of planned behavior and explaining the underlying factors. First, environmental awareness, tax revenues, and a higher independence from private utilities have an influence on mayors' attitude towards energy self-sufficiency. Second, citizens and a mayor's political environment influence the mayor's subjective norm. Third, a mayor's political power and financial resources are important factors that influence his or her perceived control. Overall, a rather long list of underlying factors influences a mayor's desire to strive for energy self-sufficiency. Based on the previous research and the extensive interviews, I provide a new classification scheme to categorize studies, including the present ones, into the spectrum of energy self-sufficiency. It classifies by type of energy carrier, spatial extent, type of self-sufficiency, degree of relative self-sufficiency, and degree of self-consumption.

In the context of the self-sufficiency of households, I contribute to the same literature streams in various ways: First, by suggesting a theoretical and broad model that explains why households purchase any kind of renewable energy system components. Therefore, I extend the theory of planned behavior to the field of households striving for energy self-sufficiency using any kind of renewable energy. The key contribution is not only a comparably generic model but also certain key findings: Compared to a couple of years before, today, perceived financial benefits and perceived autarky benefits are major drivers for households striving for energy self-sufficiency. Other drivers are environmental awareness, technology affinity, subjective norm, and perceived behavioral control. The second main contribution is the link between explaining this behavior and actual policy interventions. This link is possible due to a policy framework based on Steg and Vlek (2009), which is applied to the context of energy self-sufficiency. Actual policy recommendations

are, first, informational strategies via tailored information to address attitudinal drivers and subjective norm and, second, structural strategies via tailored subsidies to address the perceived behavioral control.

5.3 Implications for future research

This thesis offers several points of reference for future research in the fields of business models for renewable energies and energy self-sufficiency in the context of municipalities and households. While researchers applied the business model concept to solar PV, wind, and biofuel, findings on other renewable energy technologies and usages are scarce. Research should discuss more complex concepts on how business model innovation and cooperative business models could support the transition of the energy sector. For developing countries, scholars should try to find ways to conduct quantitative research and collect the necessary data to challenge or confirm the previous purely case study-based results.

In the field of energy self-sufficiency, researchers are encouraged to conduct longitudinal studies. This would enable them link to the results of the models of my papers explaining the drivers of energy self-sufficiency to actually measured behavior. Also, the effectiveness of certain policy interventions should be evaluated in longitudinal studies. For example, the effect of informational strategies, such as campaigns on the adoption rate and best practice examples of renewables on purchase intention or actual behavior.

Perceived autarky benefits are a key driver of households' attitude, which raises the question of the economic value this factor has: Studying the willingness to pay a premium due to the value of being partly energy self-sufficient would provide a quantifiable understanding for business models that might work beyond pure economic viability. First approaches can be found in the literature (Burkhalter, Kaenzig, & Wüstenhagen, 2009; Mattes, 2012).

Finally, research should further discuss the fundamental question of the extent to which policy makers should support the trend towards energy self-sufficiency. This would need to

consider advantages, such as economic and ecological effects, and disadvantages, such as effects on costs and the stability of the electricity grid or tax effects.

5.4 General implications for the policy maker

In recent years, an increasing number of researchers applied the business model concept to study economic aspects, drivers, barriers, and business model opportunities of all kinds of renewable energy technologies and concepts (Andersen, Mathews, & Rask, 2009; Christensen, Wells, & Cipcigan, 2012; Richter, 2013a, 2013b). The economic viability of renewable energies is crucial for policy makers to achieve the transition of the energy sector (Baake, 2015). Therefore, applying this concept and studying drivers, barriers, and opportunities to be able to constantly refine an accurate energy policy is of key relevance for policy makers (Chesbrough & Rosenbloom, 2002; Osterwalder, 2004; Richter, 2012; Zott, Amit, & Massa, 2011). Energy self-sufficiency is one business model opportunity and could potentially play a key role in the transition of the energy system (Deuschle et al., 2015; Müller et al., 2011; Rae & Bradley, 2012).

This thesis provides evidence for an unequivocal call from the scientific community for reliable legal framework conditions to allow for the long-term planning and support of promising new ventures. High upfront investments for renewable energy technologies and ventures are a key barrier, in particular, in the industrialized world, as highlighted in various studies (Hellström, Tsvetkova, Gustafsson, & Wikström, 2015; Vasileiadou, Huijben, & Raven, 2016; Wakkee, Barua, & Van Beukering, 2014; Yildiz, 2014). A reliable and supportive policy framework is crucial to business model innovation in all renewable fields, such as energy technologies, energy storage, smart grids, or concepts promoting electric vehicles. Besides the general legal framework, a concrete and repeated request is to ensure a well-educated workforce in the energy sector. Therefore, industrialized countries should focus on on-the-job training and developing countries in management education in the energy sector.

This thesis also provides evidence of a broad set of attitudinal, social, and control factors that explains why municipalities, on the one hand, and households, on the other hand, strive for energy self-sufficiency. Policy makers should decide whether and to which extent the policy framework should promote energy self-sufficiency. Previous studies found it beneficial to strive for energy self-sufficiency because of ecological, social, and economic advantages, such as a reduced pollution and local value generation (Abegg, 2011; Müller et al., 2011; Rae & Bradley, 2012; J. Schmidt et al., 2012). In contrast, the results of the second paper of this thesis suggest a distinction between the creation of local jobs and local tax revenues. The municipalities studied generally aim at relative energy self-sufficiency. They do not try to disconnect from the energy grid, but rather strive for a high degree of locally-generated renewable energy. Accordingly, the findings of this thesis suggest that policy makers should develop a decision-making tool for municipalities that allows them to identify the best practice approaches for the mix of renewables. Relevant factors are, for example, meteorological data, cultivable land available, economic aspects, and a system perspective. If policy makers decide to support relative energy self-sufficiency, they should address attitudinal and social factors with informational campaigns showing best practices.

In the context of private households, these campaigns need to address, in particular, financial benefits, autarky benefits and the environmental effect of supplying oneself with renewable energies. The advantages and disadvantages of energy self-sufficiency need to be thoroughly evaluated (Khalilpour & Vassallo, 2015; McKenna, Herbes, & Fichtner, 2015; Peter, 2013). However, municipalities and households striving for a certain degree of energy self-sufficiency could build a key cornerstone in and a chance for the transition of the energy sector policy makers could leverage.

The fundamental upheaval of the energy sector still lies ahead. Policy makers all over the world face the transition of the energy sector. This thesis aimed at providing theoretical and practical recommendations: By reducing barriers and supporting opportunities for business models for renewable energies, the transition of the energy sector has a chance to become economically viable faster. By addressing the multiple drivers of municipalities and households striving for energy self-sufficiency, this could also lead to a faster wide-spread adoption of renewable energy technologies.

5.5 References

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