The energy industry is experiencing new changes and challenges, driven by the intersection of decentralization, decarbonization, and digitalization. This has forced electric utilities to transfer to a more service-oriented business model. Through a comprehensive analysis, the first study identifies key strategies for electricity retailers to create value collaboratively with their private customers. These strategies include personalized offerings, energy efficiency solutions, energy communities, and integration of renewable energy sources. In particular, it focuses on the influence of private household beliefs and preferences on purchasing solar photovoltaic systems and consequently participating in an energy community. Energy communities enable consumers to buy and sell electricity directly to each other within a community-based framework, bypassing traditional energy utilities. The second study identifies various factors such as environmental concerns, affinity with technology, and economic incentives that influence households' willingness to participate in a local energy market. It offers insights into how business models can drive positive outcomes for both energy suppliers and consumers, contributing to a more sustainable and efficient energy ecosystem. The dissertation also concentrates on assessing the sustainability performance of rural municipalities in Germany, aiming to provide insights into their challenges, potentials, and best practices. By implementing a novel sustainability benchmarking system, the third study examines ecological, social, economic, and technological dimensions. Policymakers can utilize the findings to design effective policies and programs that address specific sustainability challenges in rural communities, considering local potentials and limitations.

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Driving Sustainability Through Business Model Innovation in the Energy Industry and Related Sectors

Mahdi Karami

129

E.ON Energy Research Center

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Driving Sustainability Through Business Model Innovation in the Energy Industry and Related Sectors

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Institute for Future Energy Consumer Needs and Behavior

Driving Sustainability Through Business Model Innovation in the Energy Industry and Related Sectors

Von der Fakultät für Wirtschaftswissenschaften der
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zur Erlangung des akademischen Grades eines Doktors der
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vorgelegt von

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Contents

Chapter 1

Introduction

1.1 Background, Structure, and Research Questions

The energy industry is experiencing new changes and challenges, driven by the intersection of three significant trends: Decentralization, decarbonization, and digitalization. The increasing decentralization of energy systems is due to decentralized energy generation and storage and more dynamic and cost-conscious energy consumers. Decarbonizing the energy system as part of global efforts to reduce climate change has led to developing variable renewable energy sources (VRES) such as wind and solar power. Finally, the digitalization and interconnection of electrical systems with other critical infrastructure has increased, potentially improving the quality of power supply in modern economies (Pérez-Arriaga and Knittel, 2016). These key trends are forcing many energy companies to expand their business model capabilities and drive innovation.

Recently, scholars have discussed the need for electric utilities to reform the business model, i.e., to replace the sale of electricity by providing services (Fell, 2017); however, this transition to a more service-oriented business model encounters many obstacles and challenges for energy companies (Helms, 2016). New business models are an essential driver for adopting radical and even disruptive innovations, characteristic of the "transition to sustainability" (Baden-Fuller and Haefliger, 2013; Bohnsack et al., 2014). The traditional business model for providing energy (services) involves the extraction, distribution, and combustion of fossil fuels by large centralized utilities (Shomali and Pinkse, 2016). These relied on increasing throughput consumption of energy to generate profits and tended to create a regional monopoly position for several large multinational companies that were able to exploit increasing economies of scale (Steinberger et al., 2009).

Other literature describes several new business models that could radically change how energy is generated, delivered, and consumed (Richter, 2012; Hall and Roelich, 2016; Brown, 2018). Richter (2012, 2013a,c) emphasizes that while the current business model of large utilities incorporates large renewable electricity resources, such as large wind and hydroelectric facilities, the increase of smart, distributed energy technologies (such as rooftop solar, electric vehicles), and small-scale storage will require a more fundamental change to the established business model. Several scholars emphasize that a sustainable energy system must move away from business models based on increasing the throughput of energy commodities and instead develop models that deliver valuable energy services (Hannon et al., 2013; Roelich et al., 2015). Other studies emphasize how the proliferation of smart meters, IoT-enabled devices, and blockchain technology can enable peer-to-peer business models to become increasingly viable-potentially eliminating the need for traditional energy suppliers (Davis and Cartwright, 2019; Verbong et al., 2013). Therefore, the current dissertation, which includes four chapters, utilizes various business model generation frameworks to derive optimal business models for future utilities and electricity suppliers.

Chapter two presents an empirical study investigating how electricity suppliers can create and deliver values to private customers and capture the market for themselves through innovative business models. Our exploratory study fills this research gap by collecting data from eleven different European companies and systematically analyzing them with the help of the "Business Model Canvas (BMC)" (Osterwalder and Pigneur, 2010). We provide a taxonomy and identify the applied business model patterns according to the "Business Model Navigator" (Gassmann et al., 2014). We find that electricity retailers are trying to take a more consumer-centric perspective for creating economic, social, and environmental values. They provide different energy-related products and services besides green electricity to their private customers. Moreover, the successful business models mainly focus on the increase in consumers' energy efficiency and electricity self-sufficiency.

In chapter three, we examine data from 1618 residential households collected from an online survey, including 1311 consumers and 307 prosumers. Our research aims to better understand under what circumstances these households would participate in a peer-to-peer (P2P) energy trading platform (ETP) and how business models can support such platforms to create added value for private households. Therefore, we analyze the households' beliefs concerning their attitudes, perceived behavioral control, and subjective norms according to the Theory of Planned Behavior (TPB) (Ajzen, 1991) and design business models correspondingly. In order to evaluate the developed business models' effectiveness and usefulness, we apply them to fifteen existing pioneer energy communities and platforms in Germany. we find that cost-saving and other financial benefits for households must be considered as the primary value proposition that a service provider offers. Moreover, business models that help households become more electricity self-sufficient and consume less electricity from the public grid are the second-most important source of value creation from a household's point of view.

In chapter four, we assess rural municipalities' sustainability performance in Germany and compare them with the proposed sustainability benchmarking system. For this purpose, the performance of rural municipalities in the areas of energy, environment, economy, and digital infrastructure is examined using the selected set of indicators. One result from this chapter is that the available data to explain the performance of rural communities in Germany is relatively scarce. Most databases and sustainability reports are updated every five years and do not report on performance of rural municipalities. This study also contributes to the sustainability literature by examining the most general sustainability policies, indicators, and rating systems at the rural level, and gives recommendations that will interest municipalities seeking to learn from each other.

To summarize, this dissertation aims at answering the following research questions:

- How electricity retailers can create economic, social, and environmental value for private households by offering energy-efficient solutions and capturing the market for themselves through innovative business models.

- How business models for an ideal P2P energy trading platform can be designed such that prosumers are motivated to engage with the platform and gain the necessary skills and knowledge to use it both effectively and efficiently.

- How Germany's rural municipalities can improve their sustainability performance in the fields of energy, environment, economy, and digital infrastructure.

In order to get the meaningful answers, these research questions are applied to specific problems associated with renewable electricity providers.

1.2 Scope

1.2.1 Business Models for the Electricity Retailers

The growth of the "prosumer" phenomenon, actors who actively produce and consume energy, has resulted in the growth of DERs (Parag and Sovacool, 2016). It is claimed that prosumers are critical players in a distributed and frequently democratized energy future (Hiteva and Sovacool, 2017). Through self-consumption, localized renewable energy trading, and active participation in system balancing, prosumers can help address many of the challenges associated with this new system (Parag and Sovacool, 2016). However, existing regulatory frameworks and energy markets in most developed countries are weakly adapted to this agenda, evolving with the incumbent model dominated by large suppliers (Hannon et al., 2013). Recent work has highlighted the potential of innovative business models to overcome incumbent structures and promote sustainable energy systems (Bolton and Hannon, 2016; Hall and Roelich, 2016).

Recently, scholars have discussed the need for electric utilities to reform the business model, i.e., to replace the sale of electricity by providing services (Fell, 2017); however, this transition to a service model confronts many obstacles and challenges for energy companies (Helms, 2016). The literature on energy business models has so far focused on the emergence of specific innovations in the energy value chain, including solar power generation (Karakaya et al., 2016), energy storage (Hamelink and Opdenakker, 2019), and electric vehicle (EV) charging (Madina et al., 2016). These are significant engagements for understanding how new technologies can enable new entrants to compete with incumbents. These engagements demonstrate the importance of business model research to the energy policy association by examining where business model advancements can have both beneficial and disruptive impacts on energy markets (Richter, 2013a).

Despite the countless possibilities for business model developments in electricity supply markets, the retail point of the value chain is undoubtedly less affected. The traditional utility business model has a generally simple value proposition; national utilities rely on expanding kWh units delivered (against cost) to remain profitable. In this context, Specht and Madlener (2019) also used the BMC approach to examine the business model transition process in the utility industry and identify existing regulatory barriers. They found that incumbent utilities in Germany are struggling with their business models that are unsuitable for the new challenges in power supply systems. Accordingly, they proposed a customer-centric business model for future power utilities that would act as an "Energy Supplier 2.0" (through third-party ownership) and an aggregator of energy assets for its customers.

Richter (2013a) applied the business model theory to discover how German utilities are positioning themselves concerning the challenges of the energy transition. To this end, he derived two different generic business models, including customer-side renewable energy business models and utility-side renewable energy business models. He found that utilities had developed solid business models for large-scale utility-scale renewable energy generation. However, he neglected to introduce business models for using smaller-scale customer-side renewable energy technologies, which requires appropriate organizational structures, such as separate business units for utility-side and customer-side generation and a greater focus on external partnerships. Therefore, we realized that there is still a gap in the literature that has not covered electricity retailers' business models yet. Hence, the second chapter determines how retailers can create economic, social, and environmental value for households by offering energy-efficient solutions.

1.2.2 Business Models for P2P Energy Trading Platforms

Business models play an essential role in transitioning to more sustainable energy systems (Wainstein and Bumpus, 2016). While renewable energy technologies can increasingly compete with fossil fuels in terms of their electricity generation costs, promising improvements can also be observed through complementary technologies also highly relevant from a system perspective such as batteries, smart grid devices, or software solutions (Martin-Martínez et al., 2016; Wade et al., 2010). In this context, policy support and subsidies have successfully increased the demand for and production of renewable energy technologies and reduced their investment costs (Ellabban et al., 2014). New business models are needed to move beyond the old centralized, top-down supply system and provide decentralized, bottom-up solutions involving multiple actors that create and distribute additional value and support the entire system (Richter, 2013a; Rodríguez-Molina et al., 2014).

To meet this need, "sustainable business models" ideally not only transform organizations but also contribute to sociotechnical transitions toward economic, environmental, and social sustainability (Bidmon and Knab, 2018; Schaltegger et al., 2016). In this regard, Richter (2012, 2013c) and Funkhouser et al. (2015) present three examples of utility-oriented renewable energy business models and their challenges, especially in distributed PV generation. Richter's research focuses on developed countries, identifies two generic renewable energy business models, and discusses them further to explore the barriers to business model innovation. Richter's holistic and in-depth approach, which includes business model innovation and policy support, is more typical of work that focuses on developed countries. However, several other examples of community renewable energy projects include various renewable energy technologies such as peer-to-peer (P2P) communities. Walker (2008) describes them as "community renewable activities", a part of renewable energy generation. Examples of these "community energy systems" include district heating and district cooling, which may have different ownership structures, such as municipal ownership (Juntunen and Hyysalo, 2015; Lund et al., 2010).

Peer-to-peer (P2P) markets are the least structured market designs to date and combine decentralized, independent, and flexible P2P networks that develop almost entirely from the bottom-up. These markets can also involve multiple long-term or ad hoc contractual relationships between prosuming agents or between another service provider and an energy consumer (Parag and Sovacool, 2016). P2P markets can provide opportunities for all-electric power system stakeholders (Paudel and Beng, 2018; Wilkinson et al., 2020). The introduction of such new markets also creates new business models. An example of such a business model is the P2P market model (Lavrijssen and Carrillo Parra, 2017; Sousa et al., 2019; Green and Newman, 2017), which in principle allows consumers and prosumers to trade with each other without needing a utility or retailer as an intermediary.

The existing literature on business models for P2P energy exchange communities or platforms does not propose business models from household behavior and preferences; in Germany, customer decisions in this context have hardly been studied so far. For example, Hackbarth and Löbbe (2020) identified the most promising customer segments as well as customer preferences and motivations for participating in P2P electricity trading based on a survey of customers of seven municipal utilities. They find that households with the highest propensity to participate in P2P electricity trading are motivated mainly by the opportunity to share electricity and, to a lesser extent, by economic reasons. Hahnel et al. (2020) examined the willingness of energy consumers and prosumers to participate in a P2P energy sharing community regarding consumer preferences. The authors find that electricity prices in the community and the state of charge of private energy storage systems were the most critical indicators of household trading behavior. While the authors provided new insights into the design of P2P communities, they did not suggest corresponding business models for households to participate in a P2P energy-sharing community.

Pires Klein et al. (2020) provide insights into P2P energy sharing business models that will foster the development of more complex business models for the Portuguese energy market, despite stringent regulatory constraints. The authors proposed a business model that resulted in immediate financial benefits from sharing the excess power generated by solar PV systems among end-users in the same low and medium-voltage substations. Zhang et al. (2018) review a business model and a prototype for an online trading platform called "Elecbay" during the bidding process. A four-layer system architecture model for P2P energy trading is developed and enables to present further results on the benefits of P2P energy trading. Park and Yong (2017) examined five different P2P energy trading projects based on their business models, including commercial and pilot services. Their study identified the potential development and upcoming challenges according to the business model elements of each case.

Overall, we found no empirical study yet that offers business models for P2P energy sharing platforms by addressing households' beliefs and preferences. Hence, to the best of our knowledge this study is the first one that addresses this critical knowledge gap in the P2P energy trading literature by deriving optimal business models and presenting a nationwide business model analysis of existing energy communities and platforms. The obtained results provide a more comprehensive overview for researchers studying P2P energy trading business models that are not fully explored in the existing literature. The descriptive methodological and empirical research presented aims to identify how business models for an ideal P2P energy trading platform can be designed to motivate prosumers to engage with the platform and acquire the necessary skills and knowledge to use it effectively and efficiently.

1.2.3 Sustainability Performance of Rural Municipalities in Germany

Burton (1987) has described sustainability as a "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." According to Pearce et al. (1993) the sustainability concept primarily considers the welfare of the current and next generation or the need for attaining economic growth for all human beings by respecting natural resources and environmental capability. According to Glavivcč and Lukman (2007) and Quak and De Koster (2007) three principal components of social, economic and environmental sustainability have been evidenced, which constitute the so-called "triple bottom line" for sustainable development that arose in the early 1980s (Elkington, 1994). The social domain involves the need to reduce any adverse impacts from industrial activities, while the economic scope relates to the efficiency of business operations, balancing the resources used for manufacturing products and delivering services to people. Environmental sustainability addresses the protection and preservation of natural resources for future generations.

Measuring sustainability performance is a very crucial step in sustainable development planning. Indeed, sustainability performance indicators have attracted significant attention worldwide because they are intended to deliver a reliable, long-term, easy-to-understand proxy for more expansive areas of concern for sustainable development (Wheeler, 2000). While sustainable key performance indicators (KPIs) are developed to quantify the sustainability of municipalities, it is necessary to compare them from the perspective of overall sustainability performance. However, sustainability indicators are typically considered from various domains, for example, energy, water resources, air pollution and transportation, and civil infrastructure, and the indicator categories are usually presented using a distinct unit of measurement – such as percentages, cubic meters, kilometers (Olewiler, 2006).

Sustainability KPIs are widely addressed in the literature. These indicators are also matching with the needs for transitioning the municipalities to more resilient and sustainable alternatives that will help them to work towards reaching the sustainable development of both large central and distant communities (Pires et al., 2014; Devuyst et al., 2001; Collier et al., 2013; Mori and Christodoulou, 2012). Therefore, determining an overall sustainability performance assessment becomes a challenging task that requires appropriate scientific approaches that can quantify the sustainability of diverse municipalities. Sustainability benchmarking is a crucial step to simultaneously realizing the sustainable development goals of different municipalities. However, problems and debates naturally arise about the types of indicators to include in sustainability benchmarking projects and the extent to which standardization is needed (Ramos and Pires, 2013; Pires et al., 2014). For the Germany's federal government, promoting sustainable development is a fundamental goal and benchmark of government action across the entire nation (and even beyond). Germany's federal government is committed to an ambitious implementation of the 2030 Agenda through the Sustainable Development Strategy which is taking to implement the adopted 17 Sustainable Development Goals (SDGs) of the UN at three levels – i.e. the federal, state, and municipal level (The German Federal Government, 2021b).

Luque-Martínez and Muñoz-Leiva (2005) reviewed the benchmarking concept effectively for municipality planning and delivered a systematic and steady method that identifies, comprehends, and executes the most appropriate practices and capabilities from other municipalities to improve a specific (or the own) municipality's performance. By performing similar investigations based on a theoretical evaluation and practical examinations in an urban energy system model, Klemm and Wiese (2022) have studied different indicators for optimization, benchmarking, and comparison of various urban energy systems in Germany. They recommend utilizing multi-criteria models and combining the indicators of absolute greenhouse gas emissions, energy costs, and energy demand to optimize urban energy systems. Their example scenarios show modeling strategies to optimize the sustainability of urban energy systems.

Our study aims to evaluate, and better understand the sustainable performance of rural municipalities in Germany, to set benchmarks for improving their performance, and to guide policymakers in their sustainable development policy actions. Accordingly, the objectives for the work are defined as follows:
(1) To select performance indicators for comparing rural municipalities for benchmarking.
(2) To decide the method and process of benchmarking for sustainability in terms of economic, social, environmental, and technological aspects considered.
(3) To better measure, compare, and evaluate the sustainable performance of rural municipalities.
Hence, our exploratory study is dedicated to two main research questions: Which KPIs can be used to evaluate rural municipalities' real-world performance and also enable them to compare their performance with others, and how Germany's rural municipalities can improve their sustainability performance in the fields of energy, environment, economy, and digital infrastructure.

Therefore, the original contribution of the third article to the literature is twofold. First, our methodological novelty employs "multiple methods" by evaluating the performance of rural municipalities in the fields mentioned above by employing a menu of selected indicators. Second, our study reviews the most general sustainability indicators through a top-down approach. It involves the maximum number of rural municipalities by quantitatively comparing their sustainable progress and providing the best benchmark in each category. We believe the results will also interest municipalities that are planning new, and especially capital intensive municipal projects, especially as they seek to learn from each other.

1.3 Methodology

This section briefly presents an overview of the diverse methods applied in this dissertation to answer the outlined research questions. The appropriate methodologies have been chosen and applied in each chapter, depending on the available data and the research question posed.

Research on the business model innovations in the electricity retail sector is at an early stage. Thus, the second chapter presents an exploratory study that qualitatively covers a less researched topic in the retail electricity market. It analyzes eleven different electricity retailers across Europe. We have chosen these case studies by desk research and industry experts' consultation from electricity suppliers, industry associations, and energy consultants based on five main criteria. Data were collected from primary sources (six semi-structured interviews) and secondary sources (companies' websites, news from the companies' social media channels, brochures, annual reports, and customers). Then, the coding approach is used in order to label, accumulate, and analyze the information and build up the investigation. A code can be a keyword, subject, or category within the interview transcript or the notes. The used codes include energy-as-a-service, solar photovoltaics (PV), smart home solution, electromobility solution, energy storage providers, online shop, energy management app, smart meter, and demand-side management (DSM). Based on these identified codes, the collected data are analyzed based on the building blocks of the BMC (Osterwalder and Pigneur, 2010).

BMC, which is applied in chapter 2, interprets the four fundamental fields of business: offer, customers, financial viability, and infrastructure. The BMC framework adopts a set of building blocks to describe an organization's business model that includes: (1) Key Partners, which is the network of producers and partners that run the business model; (2) Key Activities which characterize the most important things an organization must perform to run its business model; (3) Key Resources that define the necessary resources needed for a business model operation; (4) Value propositions (VPs) which define the array of products and services that make an incentive for a particular customer segment; (5) Customer segments that characterize the different groups of individuals or stakeholders which organizations attempt to access and serve; (6) Customer Relationships which describe the kinds of connections an organization sets up with particular Customer Segments; (7) Channels define how an organization speaks to its customers and manages to convey a VP; (8) Cost Structures explain all costs spent to make a business model work and, finally, (9) Revenue Streams which characterize the money an organization earns from every Customer Segment. Extraction of business model building blocks provides a systematic way of analyzing business models' internal and external features and potential opportunities for increasing social and economic VPs and mitigating environmental impacts.

We also use the Business Model Navigator approach (Gassmann et al., 2014) in order to identify the applied business model patterns. It characterizes a company's business model based on the four focal measurements: the Value, the Who, the What, and the How and it recommends a library of business model patterns as the basis for new business models which in the past were analyzed and identified. The relevant patterns for this study include subscription, pay-per-use, open business models, layer player, direct selling, solution provider, and cross-selling, which are further explained in chapter 2.

Chapter 3 employs data obtained from an online survey conducted in January 2020 among 3102 households living in Germany, which resulted in 1618 respondents, including 307 prosumers and 1311 energy consumers. All the participants own a house and decide on their energy matters independently. The survey collects data regarding households' and prosumers' beliefs and preferences towards energy, perceived financial situation, and demographics, including gender, age, education, and type of houses.

In our descriptive methodological study, we apply methodological triangulation (Denzin, 2017) as our primary form of novelty by combining TPB of Ajzen(Ajzen, 1991) with the business model concept from Amit and Zott (2012). According to the TPB, consumers may have several beliefs that shape their attitudes and perceived behavioral control and social norms. It presents a model for foretelling human behavior while implying that intention defines the behavior and is based on the assumption that behavioral intention belongs to three prominent circumstances: attitudes towards the behavior, social pressure to enact the behavior (subjective norms), and perceived behavioral control (PBC) for performing the behavior.

In order to respond to the households' beliefs, we are developing business models according to Amit and Zott's approach and configure the proposed P2P ETP by subdividing the main research question into the following six research questions:

(1) What consumer demands will the new business model serve?

(2) What unique actions could help to meet those demands?

(3) How could the actions be combined in unique styles?

(4) Who should conduct the actions and what unique governance organizations can we discover?

(5) How will economic, social, technological, and environmental value be created for every partner?

(6) What revenue streams can be adjusted to complement the business model?

The collected data from the online survey includes relevant measures for intention, e.g., attitude, subjective norm, and PBC under the TPB model. As an attitude, we measure the perceptions of the authenticity and effectiveness of PV systems and expectations in terms of cost savings and generating revenues. We also measure the affinity with technology and awareness regarding saving energy vis-a-vis participants' perceived behavioral control. Concerning subjective norms, We include the descriptive and injunctive norms established by close peers. Thus, the third chapter describes the data characteristics, including means and proportions.

The fourth chapter, which identifies the ten most important indicators for measuring sustainability, collects data from official federal and local publications. We also rely on analysis of publicly available documents, including municipality websites and publications, media articles and press releases, and academic and grey literature reviews. For this study, we use a wide range of indicators, including (1) energy and environment, (2) quality of life, (3) local economy, and (4) digitalization. There are three indicators for the energy and environment category: greenhouse gas emissions, promotion of renewable energy sources, and economical and efficient use of energy sources.

1.4 Overall Contribution of the Dissertation

The three research articles included in this dissertation contribute to the business model innovation in the energy industry. These have been published in the FCN Working Paper Series and are available via the Social Science Research Network (SSRN) as well as RePEc. Chapters 2 and 3 have been published in international peer-reviewed scientific journals:

Chapter 2 presents empirical evidence on how electricity retailers' business models are structured today and synthesizes and distills the methods that help electricity retailers redesign their business models and create economic, social, and environmental value for private customers.

The transition to a low-carbon economy is necessary to mitigate the impacts of climate change. Electricity suppliers play a crucial role in the sustainable energy transition by promoting the use of renewable energy sources, encouraging energy efficiency and conservation practices, and facilitating the integration of renewable energy into the grid. This empirical research utilizes the business model canvas and pattern methodology to investigate how retail electricity suppliers are positioning themselves and structuring their business models in line with sustainable development to create economic, social, and environmental value for their private customers. The research shows that current electricity retailers have a consumer-centric perspective and offer various energy-related products and services, including green electricity, solar PV, energy storage systems, e-mobility solutions, smart home products and services, and energy management apps. We find that the emergence of smart meters and IT solutions has enabled a few electricity suppliers to exploit innovative patterns such as digitalization to increase households' energy self-sufficiency and independence from utilities. Finally, the future outlook indicates that more electricity retailers will incorporate cross-selling, sustainable energy solutions, and digitalization patterns to their business models and offer energy services to private customers, including energy-sharing platforms, home energy management systems, and demand-side management services, further promoting sustainable energy practices and contributing to sustainable development.

This article (Chapter 2) was prepublished as:

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Chapter 3 analyzes critical novel insights about business models for P2P energy trading empirically and enables a better understanding of the topic by analyzing and identifying the business models of the selected use cases.

Households play a significant role in the sustainable energy transition. They can contribute to the achievement of sustainable development goals and promote a more sustainable future by adopting energy-efficient technologies, investing in distributed energy resources such as solar PV systems, and employing demand-side management techniques. This study, which is based on a survey of 1618 German homeowners, suggests that financial incentives are a significant factor in the decision to adopt solar PV systems and become prosumers, and households may not necessarily consider ecological or energy community-driven factors. They may participate in P2P energy-sharing platforms to save on their energy costs and increase their financial gains. We find that, despite the existence of over 2000 electricity suppliers and utilities in the German energy market in 2020, there were only a few case studies (fifteen) that offered P2P energy trading or communities for households. However, based on the key findings, it is predicted that more energy companies and utilities will adopt P2P energy trading business models and offer energy-sharing platforms to their customers in the coming years. The analysis also proposes two primary business models for future energy retailers. Firstly, company policymakers should focus on creating P2P energy-sharing communities or platforms that enable trading between prosumers and consumers in real time. Secondly, energy retailers should integrate regional renewable energy sources and supply local energy consumers. In order to increase the number of dedicated businesses developing or operating energy communities and platforms, regulatory policymakers must remove existing legal obstacles and attract new market participants, such as startups, research institutions, and investors.

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Chapter 4, as an empirical study, evaluates the sustainable performance of German rural municipalities in our proposed benchmarking system as a practical tool in terms of economic, social, environmental, and technological aspects.

standard KPIs that are widely acknowledged and corroborated by scientific publications and international organizations, we reviewed the 17 global sustainable development goals (SDGs) set by the United Nations, the World Health Organization (WHO), The World Bank and, additionally, Germany's sustainable development strategy.

Rural municipalities and communities play a critical role in sustainable development. Therefore, measuring their sustainability performance is crucial to identify areas of improvement, establish targets, and evaluate the effectiveness of policies and strategies. Our developed benchmarking tool can be used to assess and evaluate the sustainability performance of local communities. It involves comparing the performance of different rural municipalities based on various indicators that are widely acknowledged and corroborated by 17 global sustainable development goals (SDGs) set by the United Nations, the World Health Organization (WHO), The World Bank, and Germany's sustainable development strategy. Our suggested benchmarking system includes quantitative, measurable, comparable, and comprehensible indicators for energy and environment, quality of life, local economy, and digitalization dimensions, thus expanding the scope of commonly used benchmarking systems that typically focus on only one of the three spheres of sustainability (economy, environment, society).

Finally, the above article (Chapter 4) was prepublished as:

• Karami M., Madlener R. (2021). Sustainability Performance Benchmarking of Rural Municipalities in Germany, FCN Working Paper No. 11/2021, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November 2021.

and in revised form eventually as:

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The following sections briefly outline the research questions, methodology, and results of the individual articles. The full articles can be found in chapters 2, 3, and 4 of the current dissertation.

1.4.1 Business Model Innovation for the Energy Market: Joint Value Creation for Electricity Retailers and Their Customers

Electricity retailers are facing a decentralized, decarbonized, and digitalized road toward the sustainable energy transition. This paper presents an empirical study investigating how electricity suppliers can create and deliver value to private customers and capture the market for themselves through innovative business models during the low-carbon energy transition. Our exploratory study fills this research gap by collecting data from eleven different European companies and systematically analyzing them with the help of the "Business Model Canvas" (Osterwalder and Pigneur, 2010). The taxonomy and identification of the applied business model patterns are provided according to the "Business Model Navigator" (Gassmann et al., 2014). Consequently, the current research clarifies how business models of electricity retailers are structured today. We find that electricity retailers are trying to take a more consumer-centric perspective for creating economic, social, and environmental values. They provide different energy-related products and services besides green electricity to their private customers. The successful business models mainly focus on the increase in consumers' energy efficiency and electricity self-sufficiency. By linking the business model innovation and retail electricity market, recommendations for business managers and policymakers are made.

1.4.2 Business Models for P2P Energy Trading in Germany based on Households' Beliefs and Preferences

With the expansion of distributed energy resources and the phaseout of the feed-in-tariff scheme in Germany, self-consumption and electricity sharing within a community of prosumers are becoming more profitable. This paper derives optimal business models for a sustainable P2P energy trading platform in Germany. It examines data from 1618 residential households collected from an online survey, including 1311 consumers and 307 prosumers. Our research aims to better understand under what circumstances these households would participate in a P2P energy trading platform and how business models can support such platforms to create added value for private households. Therefore, households' beliefs concerning their attitudes, perceived behavioral control, and subjective norms are analyzed according to the theory of planned behavior (Ajzen, 1991), and business models are designed correspondingly. In order to evaluate the developed business models' effectiveness and usefulness, we apply them to fifteen existing pioneer energy communities and platforms in Germany. We find that cost-saving and other financial benefits for households must be considered to be the primary value proposition offered by a service provider. Business models which help households to become more electricity self-sufficient and to consume less electricity from the public grid are the second-most important source of value creation from a household's point of view. By connecting the business models and the P2P prosuming market model, recommendations for companies, policy-makers, and regulatory authorities are made.

1.4.3 Sustainability Performance of Rural Municipalities in Germany

This study assesses the sustainability performance of rural municipalities, proposing a novel sustainability benchmarking system. For this purpose, the performance of selected rural municipalities in Germany along the dimensions economic (ECO), social (SOC), ecological (ENV), and technological (TEC) is examined based on a predefined set of indicators. This benchmarking tool can assist local communities and provide them with insights on how to improve their sustainability performance. We find that the data available to explain the performance of rural communities in Germany is relatively scarce and unevenly spread. Most databases and sustainable development reports are updated only every couple of years and often do not report the performance of rural municipalities but only larger (more urban) ones. Our study contributes to the sustainability literature by examining the most general sustainability policies, indicators, and rating systems at the rural level. Adding digitalization as a technological value makes our approach more comprehensive than many others, and accounts for the important new dimension of societal transition. The recommendations provided can be of interest for municipalities seeking to either learn from each other or have some systematic, repeatable self-assessment and thus sustainability guidance over time.

1.5 Limitations

The research in this dissertation is subject to some limitations that need to be discussed. In chapter 2, we were unable to interview all the companies because the case studies were located across Europe. The secondary data are mainly gathered from the company's website. Nevertheless, all the information published on their websites and brochures is for informing the customers and stakeholders. As a result, the secondary data is still valid and reasonably accurate. While our research presents general coverage of multinational companies, the situation for the medium-sized, small-sized, and start-up results cannot quickly be investigated. The sample selection focuses on the incumbents and pioneers in each group. Thus, the study does not deliver an exhaustive analysis and overview of the retail electricity market situation but rather highlights the most important companies selected from advanced business model innovations and developments. We do not explain the companies' entire business model; rather our study simply explains how a company is applying a unique pattern to build a more competitive business model.

In chapter 3, the results reflect a survey sample consisting of 1618 HHs in Germany (excluding commercial and industrial buildings), including 307 prosumers and 1311 energy consumers, which may deliver potentially biased results. Especially where the ratio of participants is considerably different from the German population statistics in terms of participants' gender, age, education, and – more importantly – their disposable net income. As business models are dependent on different circumstances and settings, such as regulatory limitations, we have not tested the proposed business models yet on any P2P energy trading platform to check whether they might be successful in practice or not. This can be done in principle, and that consumer acceptance of business models, and thus diffusion/upscaling, impact commercial success because of economies of scale and sunk costs to be recovered, e.g., for smart grid technology investment. Since most business case studies are at their early stage and do not publish any financial reports of their operation, we could not find sufficient data to assess their business models. Additionally, since P2P electricity trading platforms are relatively unknown opportunities for households, we do not ask them directly in the survey about these and how they operate them. However, we just point to the opportunities they can offer prosumers based on our in-depth literature review. In our study, we do not use the households' electricity usage pattern. Therefore, the usage patterns are crucial for the volume of P2P trading possible.

In chapter 4, we collect data from official federal and local publications. we also rely on analysis of publicly available documents, including municipality websites and publications, media articles and press releases, and the academic and grey literature review. Because the data collection process has limitations, we move from a definitive list to a real list. Another crucial issue is that the available data for announcing the performance of rural municipalities in Germany is relatively poor. Most databases and sustainability reports are updated every five years and do not capture the performance of rural municipalities. However, we benchmark over time and compare the obtained charts using the most recent data received. Although the selected set of indicators is comprehensive, they are not specifically designed for the rural level. Thus, some economic or environmental dependencies might be identified when monitoring rural municipalities.

1.6 Future Research

The findings of the present dissertation open several avenues for future research. In chapter 2, we analyze the business models of eleven different European companies systematically. If quantitative data – such as the number of customers, cost structure, and revenue streams – of the applied business models were available, the business model's success could be examined as well. Moreover, since the sustainable energy transition is in progress and requires more research in business model innovation, future research could also relate to the business models for the prosumers' households, energy-sharing platforms, and market designs for enabling peer-to-peer (P2P) business models.

Consequently, regarding the development of business models for P2P energy-sharing platforms, future research needs to apply, adapt, and promote the suggested business models in chapter 3 and measure their success quantitatively. Moreover, it needs to focus on the implementation of sustainable business models on P2P energy trading platforms. Specifically, since studies in this field are still rare, future research can address business model issues by gathering survey data from members and interviewing stakeholders of real-world P2P energy trading companies and projects.

The sustainability performance evaluation for rural municipalities in Germany, performed in chapter 4, yields additional insights into promoting renewable energy sources. Having up-to-date information regarding the current capacity of renewable energy sources and the installed technologies will enable future research to design real and more precise benchmarking systems. We also suggest future research to develop more sustainable measures for other energy-related key performance indicators, such as efficient use of energy sources.

1.6.1 Author's Contribution to the Individual Chapters

The author's contribution to chapter 2 can be summarized as follows:

- Contribution to the formulation of research questions
- Investigation, methodology, validation
- Data collection and processing

- Analysis and evaluation of the obtained results and visualization
- Writing the original draft of the manuscript.

The author's contribution to chapter 3 can be summarized as follows:

- Data curation and formal analysis
- Investigation, methodology, validation
- Contribution to the formulation of research questions
- Contribution to analysis and evaluation of the obtained results
- Writing the original draft of the manuscript.

The author's contribution to chapter 4 can be summarized as follows:

- Formulation of research questions
- Data collection and processing
- Contribution to the formulation of research questions
- Analysis and evaluation of the obtained results
- Writing the original draft of the manuscript.

Chapter 2

Business Model Innovation for the Energy Market: Joint Value Creation for Electricity Retailers and Their Customers

2.1 Introduction

The energy industry is experiencing a new set of changes, driven by the crossing point of three key trends: decentralization, decarbonization, and digitalization (the "3Ds"). The increasing decentralization of power systems due to the development of distributed energy generation and more dynamic and cost-responsive energy consumers. The decarbonization of the energy system as part of global climate change reduction efforts has resulted in the development of variable renewable energy sources (VRES) such as wind and solar energy. Finally, the digitalization and inter-connectedness of electrical systems with other critical infrastructure has increased, which improves the quality of power supply in modern economies (Pérez-Arriaga and Knittel, 2016). These key trends are compelling many energy companies to increase their business model capabilities and innovate on them. The objective of the current exploratory research is to explore and better understand how business model innovation and technology trends have influenced electricity suppliers in the retail electricity market; therefore, the other electricity markets – such as generation and wholesale markets – are excluded and beyond the scope of our analysis.

In many countries, the opening of the [retail] market was pursued by a two-fold inflow. Initially, recently start-ups penetrated in the retail electricity market, examining new business models. Their activities were focused on retail supply (branding, value-adding services, customer relationships), endeavoring to benefit from a low-cost, responsive, and flexible organizational structure. Second, new market entrants arose from a different industrial sector or other geographical zones and expanded into the residential electricity market, competing with their regional or national incumbents (Defeuilley, 2009).

Scholars have recently discussed the need for electricity suppliers to reform their business model, i.e., replacing the selling of electricity as a commodity with the provision of services (Fell, 2017); however, this transition to a service model encounters many obstacles and challenges for energy companies (Helms, 2016). Responding to the sweeping changes in the energy industry due to the "3Ds" - has created different impacts. As a result, new companies position themselves in the energy sector and offer new products, services, and energy supply conditions. Overholm (2015) has shown that these new entrants construct their position in the electricity market by developing new business models based on innovative and often digitalized services, creating a new ecosystem and involving new partnerships.

Regarding this, the retail electricity market creates new business model challenges for the retailers and forces them to develop their business models further in order to remain competitive during the sustainable energy transition. Richter (2013b) investigates the business model opportunities and challenges for the German utilities in electricity generation from renewable energy resources, whereas Specht and Madlener (2019) also examines the challenges of the transition towards distributed power generation for energy suppliers. Niesten and Alkemade (2016) review the business models for creating and capturing value by offering smart grid services such as vehicle-to-grid and grid-to-vehicle services, demand response services, and services to integrate renewable energy. Braunholtz-Speight et al. (2020) study the business models and financial characteristics of UK community energy projects with the 'Business Model Canvas' and thoroughly investigated price guarantee mechanisms. Therefore, we realized that there is still a gap in the literature that has not yet covered electricity retailers' business models. Hence, our exploratory research tries to determine how retailers create economic, social, and environmental value for households by offering energy-efficient solutions.

To address the research question, eleven different electricity supply companies across Europe are investigated. The data collection process for companies applying various business models is analyzed and sorted out systematically with the help of the "Business Model Canvas (BMC)," a tool for managers developed by Osterwalder and Pigneur (2010). Afterward, the applied business model patterns are clustered and identified according to the "Business Model Navigator" (Gassmann et al., 2013). Thus, the original contribution of our exploratory empirical paper is to shed light on how electricity retailers' business models are structured today. The research finally synthesizes and distills the methods which help electricity retailers to renew their business models and create economic, social and environmental value for private customers. However, we are not charting the evolution of energy utility business models but merely use an analytical framework that allows us to provide a current snapshot of their characteristics.

The remainder of this paper is organized as follows. Section 2 presents the conceptual background and the theoretical frameworks to which the research question is related, i.e., the BMC, "Business Model Navigator," business model innovation, and business model innovation in the energy industry. The detailed methodology of this qualitative research is described in section 3. The results of the analysis are presented in section 4. The discussion follows in section 5. Finally, the conclusions and implications of this study are drawn in the concluding section 6.

2.2 Conceptual Background

Over the last years, interest in the concept of business models and business modeling has started attracting the attention of both managers and academics. While the research in the field of business model development has traditionally concentrated on business activities, the development of new organizational architectures arranged for ambitions other than economic profits, such as solving social issues and sustainability problems, has begun to attract business model researchers and business model developers alike (Seelos and Mair, 2007; Yunus et al., 2010).

According to Teece (2010), companies have always performed according to a business model, at least until the mid-1990s. He remarks that business models have been a fundamental part of economic behavior since pre-classical times. Admittedly, companies have always performed according to a business model. However, until the mid-1990s, they traditionally operated the following similar logic that a product/service typically was produced by the company and passed to a consumer from which revenues were generated. Even if cases of companies and organizations adopting innovative business models have been identified in business history, it is only recently that the scale and speed at which innovative business models are transforming industries and, indirectly, civil society has attracted the scholars' attention. Zott et al. (2011) explore the application of the term business model in general management studies and note an exciting increase in the frequency over the time period 1995 and 2010, in line with the popularization and widespread distribution of the Internet.

Magretta (2002) believes that the business model is a concept that answers four questions: (1) who is the customer, (2) what is the consumer value, (3) how do we generate revenue in this business, (4) and what is the economic rationale that defines how we can give value to consumers at an applicable cost? According to Jonker (2012), the three fundamental values that innovative business models can create are social, economic and environmental. Sustainability can be explained as a broad overarching value, one in which the shared values are fixed. It is not something in itself that requires to be composed with the rest. All companies have a business model, whether they make it explicit or not. At its core, a business model offers two primary purposes: value creation and value capturing (Chesbrough, 2007).

When Zott et al. (2011) considered the most recent literature on the business model topic, they noticed that different conceptualizations exist. In any case, they also noted that in the literature, some essential topics are developing that frequently appear among the different conceptualizations of the developed business model. Individually, researchers appear to perceive—explicitly or implicity—that the business model is a system-level idea, fixated on activities and concentrating on value. It accentuates a fundamental and integrated understanding of how an organization's system of activities for value creation is arranged.

Additionally, it was noticed that the phenomenon of value creation, as illustrated by the business model, commonly takes place in a value network (Normann and Ramirez, 1993), which can incorporate providers, partners, distribution channels, and coalitions that broaden the organization's assets. Subsequently, it is recommended that the business model likewise presents a new unit of analysis further to the firm, product, industry, or system levels. Such a new unit of analysis is established between the firm and its network of exchange partners (Massa and Tucci, 2013). These discussions recommend that, at first glance, the business model might be conceptualized as depicting the logic of how an association (a business firm or other type of organization) makes, conveys, and catches value (social, economic, or different types of value) in association with a system of exchange partners (Afuah and Tucci, 2003; Osterwalder and Pigneur, 2010; Zott et al., 2011).

2.2.1 Business Model

Historically, the business model has its foundations in the late 1990s when it was developed as a trendy expression in popular papers and media. Since then, it has raised significant attention from the researchers and experts and today forms a distinct aspect in various research streams. Generally, the business model can be characterized as a unit of investigation to depict how the business of an organization operates.

More individually, the business model is frequently characterized as an overarching concept that takes note of the various segments and assembles them all (Demil and Lecocq, 2010; Osterwalder and Pigneur, 2010). The business model concept helps managers as a management tool to plan, execute, act, adjust, and control their business (Johnson, 2010; Wirtz et al., 2010).

However, the business model explanation and the concept of Osterwalder and Pigneur are often used since they have been widely tested in practice and have been effectively applied to the energy sector (Specht and Madlener, 2019).

Business Model Canvas

In the BMC (see figure 1), a business model can perfectly be defined by nine fundamental building blocks that exhibit the rationale of how an organization aims to generate revenue and deliver value in return. They interpret the four fundamental fields of business: offer, customers, financial viability, and infrastructure. The nine-building blocks of a business model are named: Key Partners, Key Activities, Key Resources, Value Propositions, Customer Relationships, Channels, Customer Segments, Cost Structure and Revenue Streams (identical to value catching), and are summarized in the following.

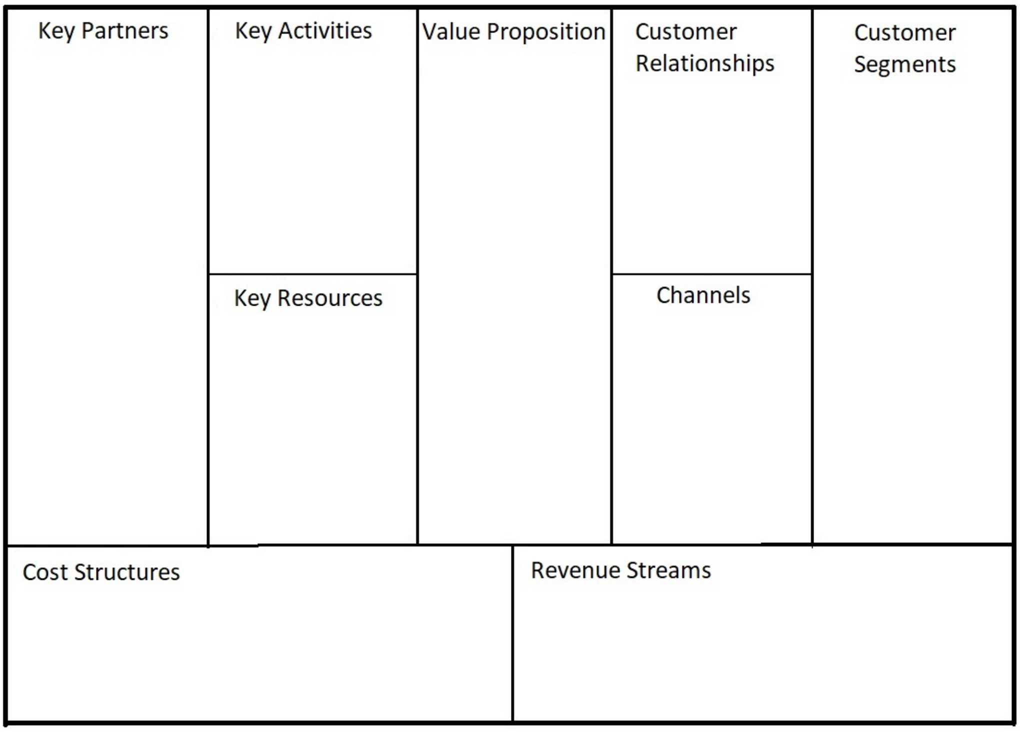

Figure 1. The building blocks of the Business Model Canvas.

Source: Own illustration, based on Osterwalder and Pigneur (2010)

1. Key Partners:

The "Key Partners" building block defines the network of producers and partners that run the business model. Organizations build alliances in order to advance their business models, decrease risk, or acquire assets. The three different motivations for building partnerships are the economy of scale and optimization, risk reduction and uncertainty, and acquisition of specific assets and activities.

2. Key Resources:

The "Key Resources" building block defines the essential resources needed for a business model operation. Every business model needs Key Resources. These resources let an organization create and deliver a value proposition, obtain markets, support relationships with customer segments, and generate revenues. Key Resources can be described as being physical, intellectual, human, and financial.

3. Key Activities:

The "Key Activities" building block characterizes the most vital things an enterprise must perform to run its business model. Key Activities are the essential actions an organization must do to work effectively. Key Activities are needed to create and deliver a Value Proposition, obtain markets, support Customer Relationships, and generate credit. Key Activities can be classified as production, problem-solving, and platform/network.

4. Value Propositions:

The "Value Proposition" building block defines the array of products and services that make an incentive for a particular customer segment. The Value Proposition is the motivation behind why customers change from one company to another. It takes care of a client issue or fulfills a client requirement. Each value proposition includes a selected array of products as well as services that oblige to the prerequisites of a particular customer segment. In this regard, the value proposition is a package of advantages that an organization offers to its customers.

Some value propositions might be inventive and present a different or disruptive offer. Others might be identical to existing business sector offers but include highlights and traits. A value proposition makes an incentive for a customer segment through a recognizable mix of components fulfilling that segment's requirement.

5. Customer Relationships:

The "Customer Relationships" building block portrays the kinds of connections an organization sets up with particular Customer Segments. An organization ought to explain the sort of relationship it needs to build up with each customer segment. Connections can extend from the individual to automated services. A few classes of Customer Relationships are recognized, which may exist together in an organization's relationship with a specific Customer Segment such as personal assistant, self-service, and automated services.

6. Customer Segments:

The "Customer Segments" building block defines the diverse groups of individuals or organizations an enterprise endeavor to access and serve. In order to improve customers' satisfaction, a company might arrange them into specific segments with standard requirements, essential characteristics, or different properties. There are distinctive types of Customer Segments: mass and niche markets, segmented, multi-sided and diversified platforms/markets, etc.

7. Channels:

The "Channels" building block defines how an organization speaks to its customers and achieves it to convey a value proposition. Channels are clients' meeting points that strengthen the customer experience and deliver a few purposes, such as increasing consciousness between clients about an organization's products and services, supporting customers to assess an organization's Value Proposition, assisting customers to buy particular products and services, conveying a Value Proposition to clients, and offering post-buy client support.

8. The Cost Structures:

The "Cost Structures" building block defines all costs spent to make a business model work. This building block depicts the essential expenses during the execution of a specific business model. Making and conveying value, keeping up Customer Relationships, and earning profit all incur costs. Cost Structures can have qualities such as fixed costs, variable costs, economies of scale, and economies of scope.

9. The Revenue Streams:

The "Revenue Streams" building block characterizes the money an enterprise earns from every Customer Segment. If clients include the core of a business model, Revenue Streams are its veins. A business model can include two distinct kinds of revenue streams: transaction incomes due to one-time client installments, and recurring incomes due to progressing installments to convey a Value Proposition to customers (Osterwalder and Pigneur, 2010).

Business Model Navigator

Business model patterns can describe proven solutions to recurring business model design (Abdelkafi et al., 2013). According to Osterwalder et al. (2020), business model patterns are a repeatable configuration of various business model building blocks aimed at strengthening a company's overall business model. Usually, business models are a recombination of existing business model patterns (Gassmann et al., 2014); therefore, by building upon features that have already been proven to be successful for different companies and industries, business model patterns are an efficient way to undertake business model innovation (Abdelkafi et al., 2013).

To characterize the business models [pattern] throughout the research, a conceptualization that comprises four focal measurements: the Value, the Who, the What, and the How are employed. This idea is easy to apply because of the reduction to four dimensions; however, it is sufficiently comprehensive to give a visible image of the business model architecture. The business model of an organization is achieved by noting the four related questions and explaining (1) the value proposition towards the customer, (2) the objective customer, (3) the value chain behind the formation of this value, and (4) the revenue model that captures the value (Gassmann et al., 2013).

Business innovation study is yet a new phenomenon; Gassmann et al. (2013) have used a two-step method to evaluate the basic patterns of business models. In that study, 250 business models that had been employed in various industries within the last 25 years were considered. Consequently, 55 patterns of business models presented as the basis for new business models in the past were analyzed and identified (Gassmann et al., 2012, 2013). Out of 55 identified patterns, the eight which are frequently employed in the energy case later on (see section 2.3) are introduced below:

Subscription: In the subscription pattern, the consumer pays a standard charge, regularly on a month-to-month or a yearly premise, intending to connect to a good or service. While clients mostly take advantage of the decreased application costs and general service accessibility, the organization creates a more steady revenue stream.

Pay-per-use: With the pay-per-use model, the real utilization of a product or service is measured. The client pays based on actual consumption. The company can bring customers who hope to make a profit by the extra adaptability, which may be more expensive.

Open business models: In the open business models, a central source of value creation is obtained due to collaboration with partners in the ecosystem. Companies following an open business model effectively have been looking for novel methods for cooperating with customers, providers, or complementors to open and expand their business.

Layer player: A layer player is a particular company constrained to the provision of one value-adding act for various value chains. This value is usually offered within different free markets and businesses. The firm profits from economies of scale and frequently manufactures more proficiently. Moreover, the learned particular skills can enhance quality.

Direct selling: It indicates a situation whereby the products and services of the firm are not sold through go-between channels, but they are accessible straightly either from the producer or service provider. In this manner, the retail margin or any extra costs related to the intermediates is skipped. These investment funds can be sent to the customers and used to establish an institutionalized deal's experience. Also, Customer Relationships can be enhanced because of such close contact.

Solution provider: A full-solution provider offers all the different types of goods and services in a specific area, centralized manner via a one-contact point. Particularly tacit knowledge is provided to the client in order to raise productivity and execution. Also, close contact with the customer fosters a deep understanding of propensities and requirements, which can enhance the products and services.

Cross-selling: In this pattern, products or services from a previously ignored industry are included in the portfolio, thus utilizing existing critical assets and abilities. Especially in retail, companies can bring extra goods and recommendations that are not connected to the core business on which they were formerly engaged. In this manner, extra revenue can be generated by only moderately imposing some changes to the current framework and resources, since more possible customer requirements are fulfilled (Gassmann et al., 2013).

Digitalization: This is a model that is combined with the digitization pattern. The digitization pattern leans on the possibility to turn existing services or products into digital variations, in order to provide favorable circumstances over tangible products or faster and simpler distribution (Gassmann et al., 2013). It also employs any other products or services to disrupt the current industry and value chain and create a new era by well-going from analog to digital. (Digitalization, in contrast to digitization, is the use of digital technologies to change a business model and provide new value-producing opportunities; it is the process of moving to a digital business.)

In order to accomplish useful business model innovations inside an organization, it is essential to acknowledge the significance of business model innovation and execute a successful business model innovation process within the company. This step is the most difficult and important one. During the business model innovation process, managers benefit from different developed tools. The future contest for comparative competitive advantages has changed from one involving pure services and products to one involving business models. Companies are required to prepare for that race. Recognizing the opportunity is not sufficient; innovators and business visionaries need to catch the opportunity and start moving (Gassmann et al., 2013).

2.2.2 Business Model Innovation

The literature at the intersection of the business model idea and the innovation field has progressed two corresponding views for the business model development. First, business models enable inventive firms to commercialize new ideas and advances. This is mostly established in the literature on entrepreneurship and technology management. There is no economic value in innovative technologies or ideas *per se*; however, only potential ones. Through the framework of suitable business models, administrators, and business, people might have the capability to open the output from investments in research and development and connect it to a market. The business model turns into a vehicle for innovation by permitting the commercialization of novel technologies and thoughts (Chesbrough, 2003).

Second, organizations can likewise regard the business model as an origin of development in and of itself, or as an origin of competitive advantage. The business model provides a different dimension of newness itself, which goes over the conventional methods of process, product, and authoritative innovation. This new measurement of innovation might be the origin of the unrivaled execution of a business model, even in developed industries (Zott and Amit, 2007). Markides (2013) supports the literature on ambidexterity to encourage organizations in their business model innovation-decision to either 'separate' or 'integrate' various strategies. However, his offering mostly rests on the preparation of conceptual guidelines.

Expand on the literature at the connection between innovation and the business models; the business model innovation may relate to (1) the outline of novel business models for recently developed companies, or (2) the restructuring of current business models. Researchers pointed out to the first view by applying the term “business model design”, which explains the entrepreneurial progress of making, executing, and approving a business model for a recently shaped company. The term “business model reconfiguration” is used to capture the phenomenon by which managers reconfigure authoritative assets (and secure new ones) to adjust a current business model. Along these lines, the procedure of reconfiguration entails shifting, with various extents of radicalism, from a current model to another one. It is argued that both phenomena are phenomena of change and could result in business model innovation (Massa and Tucci, 2013). Teece (2010) argues that business model innovation can contribute a pathway to competitive advantage if the pattern is adequately distinguished from, and challenging to replicate for both, other established companies and new competitors.

However, not all plan or reconfiguration attempts will surely result in a business model innovation. In order to be an origin of business model innovation, the output of outline or reconfiguration exercises should be described by some level of curiosity or uniqueness. Mainly, business model innovation might result in the product of outlook as well as the reconfiguration of advanced and current business models. Business model innovation establishes a subset of the more significant set involving the entire result of a business model plan and reconfiguration exercises (Massa and Tucci, 2013).

While sharing the potential for a similar result (namely the business model innovation), reconfiguration and planning are two particular actions that mean essential diversities. For instance, since the reconfiguration implies the presence of a business model, it includes, on the one hand, confronting challenges that are distinctive to the current company – for example, organizational inertia, management processes (that may hinder or cultivate change), change methods, organizational learning methods, and ways which might not be a problem in recently formed companies. On the other hand, recently shaped companies might confront different issues, such as the significant technological uncertainty, absence of resources, absence of legitimacy, and, more generally, liability of newness, which involves the outline and approval of the advanced business models (Massa and Tucci, 2013).

Other business model innovation frameworks such as Amit and Zott (2012) can be executed in several forms. For instance, by adding novel activities content, by linking activities in unique ways to structure — or by substituting one or more partners that perform any of those governance activities. The content refers to the selection of activities to be executed while the structure of an activity refers to how the activities are combined, and in what order and the governance describes who conducts the activities. Their study explains that entrepreneurs and managers must look behind the product and process and concentrate on innovating their business model in an increasingly interconnected world, especially when financial resources are scarce.

2.2.3 Business Model Innovation in Energy Industry

Since the early 21st century, in the course of widespread market liberalization, innovations in the retail electricity market were often restricted to the combined sale of electricity and gas, the development of contract menus where contracts were differentiated in terms of duration, payment method, the source of electricity (incl. green electricity products), pricing selections, or the development of value-added services (Littlechild, 2006; OFGEM, 2007).

The business model innovation literature in the energy domain has so far concentrated on the formation of particular innovations in the energy value chain, including solar electricity generation (Karakaya et al., 2016), energy storage (Hamelink and Opdenakker, 2019), and electric vehicle (EV) charging (Madina et al., 2016). These are significant commitments to our comprehension of how new technologies can empower new participants to contend with incumbent companies. These commitments show the significance of business model research to the energy policy association, as they investigate where business model advancement can have both beneficial and disruptive impacts over energy markets (Richter, 2013b).

Despite the endless possibility for business model innovation in power supply markets, the retail point of the value chain is undoubtedly less concerned. The conventional energy supply business model performs a generally straightforward value proposition; national utilities depend on expanding kWh units delivered (for costs) to stay beneficial (Blyth et al., 2014; Hannon et al., 2013). In this regard, Specht and Madlener (2019) also used the BMC approach to investigate the transition process of business models in the energy supply industry and to identify the existing regulatory obstacles. They realized that Germany's incumbent energy suppliers struggle with their business models, which are not appropriate for facing the new electricity supply challenges. Accordingly, they have proposed a customer-driven business model for future electricity suppliers that would act both as an energy supply contractor (through third-party ownership) and an aggregator of energy assets for its clients.

Richter (2013b) applied the business model concept to determine how German electricity suppliers position themselves with regard to the energy transition challenges. To that end, he derived two different generic business models, including customer-side renewable energy business models and utility-side renewable energy business models, finding that energy suppliers had developed solid business models for large-scale utility-side renewable energy production. However, they ignored to adopt business models to capitalize on small-scale customer-side renewable energy technologies, which demands appropriate organizational structures – such as separate business units for utility-side and customer-side generation and an enhanced concentration on outside partnerships.

Being clear about value proposition and value capturing is the primary purpose of the business model innovation literature. This is critical for the energy business models since they can provide numerous advantages beyond the services to the energy clients, i.e., to the energy system itself, such as demand-side management that decreases the need for strengthening networks or building new generators (Hall and Foxon, 2014). In the light of value creation and capturing for smart grids, literature shows that innovative business models have been applied for vehicle-to-grid, grid-to-vehicle services, and renewable energy integration. However, concerning demand response services and other services that extend the integration of renewable energies, insights from the literature remain restricted to value creation and capture for system operators, service providers, and consumers. The pilots show that consumers' value most often relates to lower energy consumption and lower energy bills, whereas the system operators' value is concerned with decreased peak demand and upgraded system reliability. The pilots do not contribute any sign or discussion on business models, and they do not discuss how service providers can capture value by offering smart grid services (Niesten and Alkemade, 2016).

Business model innovation is assumed to be a driver of competition in the retail electricity market. For innovators, rather than imitators, there is an incentive to invest in research and development, to establish new production and management processes (organizational not just product and process innovation), and to improve new products and services. Nevertheless, the introduction of competition in the retail electricity supply market has not motivated suppliers to successfully develop business model innovations that empower them to challenge the incumbents' positions. (Defeuilley, 2009).

2.3 Methodology

This is an exploratory study that covers a less researched topic in the retail electricity market qualitatively. Thus research on the business model innovations in the electricity retail sector is set at an early stage. The research question is selected based on filling the research gap and the authors' motivation for supporting business managers and policymakers during the sustainable energy transition in the field of business model innovation for the retail electricity market. Our research question explores how competitive electricity retailers can create a range of economic, environmental and social value for their residential customers by offering energy-efficient solutions and capture the market for themselves through innovative business models. Kim and Mauborgne (2014) believe that a business model developed in strategic pricing, excellent utility, and target costing can generate value innovation. Despite the examination of traditional technology innovators, value innovation is fixed according to a win-win competition between customers, businesses, and society.

According to Yin (2009), a case is a practical examination that investigates a modern phenomenon within its real-life setting, mainly when the limits between phenomenon and context are not visible. As a result, a case study design is selected corresponding to Yin (2009) since (a) the research question is a 'how' question, connected with discovering the actions that an organization makes to adjust to the context change; (b) the experts cannot guide or affect the execution of the events; (c) the context is connected to the phenomenon under the investigation, and (d) the inquiry may need an in-depth analysis of a particular problem.

Furthermore, Yin (2009) has suggested that given a situation that allows us to choose from different resources, a multiple-case study design should be adopted instead of single-case designs. Because the analytic conclusions will be more compelling and robust when coming from a variety of cases rather than a single case, a total of eleven different cases have been chosen in the research design. The case studies are selected by desk research and industry experts' consultation from electricity suppliers, industry associations, and energy consultants. The units of analysis are the following enterprises (primary sources of information used in brackets): E.ON (E.ON SE, 2018a,b), innogy (innogy SE, 2018, 2017), Greenpeace Energy (Green-Peace-Energy, 2018; Greenpeace-Energy, 2018), N-ERGIE (N-ERGIE, 2018a,b), Sonnen (Sonnen-GmbH, 2018), Vattenfall (Vattenfall-GmbH, 2018; Vattenfall-AB, 2018), Fresh Energy (Fresh-Energy, 2018), GridX (GridX, 2018), EDP (EDP, 2018a,b), Good Energy (Good-Energy, 2018a,b), and Oekostrom (Oekostrom-AG, 2018b,a). Our sample collection focuses on the important utilities and pioneers in each cluster. Thus, this study does not deliver an exhaustive analysis and overview of the retail electricity market situation, but rather highlights the most important ones among a selection of advanced business model innovations and developments analyzed.

Moreover, it is most likely an exploratory contextual analysis because this study aims to develop a better understanding of a specific topic. When conducting this research, we observed that the prior works/previous studies that can be referred to seem to be very few. The main focus of this research is the electricity retailers' approach with the value creation in terms of providing energy-efficient solutions for residential customers.

2.3.1 Setting

For a homogeneous product such as electricity, opportunities for marketing, and transformation (introduction and bundling, packaging) are restricted. Retailing represents only a small portion of total electricity bills because of this reason. The potential demand for an electricity supplier to meet is constrained by the low income created by the retailing activity. The product homogeneity makes it hard to offer diversification (green electricity, locally produced is the exception). The possibility of generating value-added services is accordingly limited.

In a fully liberalized market, the retail energy market does not present many profitable opportunities for new competitors. The introduction of competition into the retail electricity market ought to provide the products that consumers need to decrease the costs and barriers to entry, to support innovation, and to empower competition in generation. From this point of view, the outcomes of the introduction of competition into the retail electricity market could go far beyond the decrease in commercialization costs, which is desired by consumers (Defeuilley, 2009). This is possible through business model innovation, which enables electricity retailers to strengthen their business model and prepare to adapt their way of operating in the retail market.

2.3.2 Case selection

This research contributes to the business model innovation literature on electricity retailers in Europe. Therefore, only cases with the following five main criteria were chosen: Our research only concentrates on the companies which (1) are active in the retail electricity market and provide electricity and other ancillary products and services for (2) households and private customers – namely Business to Customer (B2C) – while the supplied electricity is generated from (3) renewable energy resources such as hydropower, wind, solar PV, and biomass, etc., (4) offer a range of Value Propositions – such as funding local projects, cutting CO_2 emissions and reducing energy bills – and have (5) more than one Revenue Streams in their business model. To classify the case studies, we have identified four organizational categories according to the companies' size and scope (see Table 1). The size of the firms refers to the annual revenues in 2017.

Table 1. Categorization of case study companies incl. revenue, total power sale and the number of private customers in 2017.

Category	Company	Revenue	EBIT	Power generation	Employees	Customers
Multinational companies >€10 bn	E.ON	€38 bn	€3,074 m	193.4 TWh	42,699	21.1 m
	innogy	€43.1 bn	€2,816 m	262.4 TWh	42,393	15.9 m
	EDP	€18.2 bn	€2,318 m	70.0 TWh	11,657	9.9 m
	Vattenfall	€13.2 bn	€1,814 m	127.3 TWh	20,041	6.5 m
Medium-sized companies €100 m - €10 bn	N-ERGIE	€2.81 bn	€171.1 m	14.2 TWh	2,447	N.A
	Greenpeace	€110.6 m	€2.14 m	379.3 GWh	94	121,600
	Good Energy	€118.9 m	€9.74 m	87.6 GWh	317	250,000
Small-sized companies €10 m - €100 m	Oekostrom	€28.8 m	€1.613 m	80.5 GWh	33	341,000
	Sonnen	€65 m	N.A	0	600	+40,000
Start-ups <€10 m	Fresh Energy	N.A	N.A	0	32	+1000
	GridX	N.A	N.A	0	30	+1000

2.3.3 Data collection

According to Yin (2009), the research approach is employing various techniques for data collection. The selection of companies in the four categories was conducted following Yin's method to satisfy the broadest conceivable spectrum of electricity retailers' business models. There are six primary sources of collecting data, each of which has its specific strengths and weaknesses. For the analysis we follow a mixed methods approach. Data analysis from the recorded interviews was conducted in a three-step process. First, the answers were coded according to the nine elements of the BMC. Second, the coded results were matched according to the patterns identified in section 2.1.2. Finally, to enable a complete analysis and discuss the interview results, the coded results were categorized. Documentation and interviews are the two primary sources of data collection applied in this study.

Primary Data: The primary data collection approach was based on different types of semi-structured interviews, including face-to-face interviews, and sending questionnaires. The interview participants comprise consultants, project managers, and sales managers, particularly from the business model development or the renewable energies department. All interviewees were provided with a semi-structured questionnaire that conducted the interviews. Five interviews were conducted face-to-face in 2018 and one online via Zoom software in spring 2020. The length of the interviews ranged from 35 to 125 min. The conversations were recorded and accordingly transferred to written protocols. Because the interviewees asked for anonymity, the quotes in the results section were given without reference to the company name. Some e-mails with questionnaires were sent to the potential interviewees, but no relevant answer was received. Therefore, the interviews for this research include one online and five face-to-face interviews. Table 2 shows the source of data collection, and Table 3 illustrates the interview settings.

Secondary Data: Several sources of secondary data collection for the in-depth analysis of the case studies were selected. The secondary data is mainly gathered from the companies' websites, brochures, and customers. We conducted short semi-structured interviews with customers to collect data about the services they get from the companies investigated. Since all companies are publicly registered in an energy supply market, all the information required to inform the public and their stakeholders are published on their websites and annual reports. The documentation contains a large number of reports gathered from the companies' websites, news from the companies' social media channels, brochures, annual reports, and customers.

Table 2. Interview details.

Company	Interviewee position	Duration
E.ON	2 Junior and 3 Senior Consultants	125 min
innogy	2 Sales Managers	65 min
EDP	1 Project Managers	55 min
Vattenfall	1 Portfolio Manager	35 min
Fresh Energy	1 Sales and 1 Project Manager	45 min
GridX	1 Sales Manager	45 min

Note: Interviewees of some company interviewed jointly.

Table 3. Sources of data collection.

Company	Website	Brochure	Interview	Customers
E.ON	X	X	X	X
innogy	X	X	X	X
Vattenfall	X	X	X	X
EDP	X	X	X	
N-ERGIE	X	X		
Greenpeace	X	X		X
Good Energy	X	X		
Oekostrom	X	X		
Sonnen	X	X		X
Fresh Energy	X	X	X	X
GridX	X	X	X	X

2.3.4 Data analysis

Coding is an approach that is presented as a means to label, accumulate, and analyze the information, and as the reason for building up the investigation. A code can be a keyword, subject, or category within the interview transcript or the notes (Wilson, 2014). With the thought of data legitimacy and reliability, this contextual analysis entirely followed the strategy of coding, gathering information, and analyzing data. The information analysis contains not only primary data but also secondary data. There are several terms and definitions which are used in this research:

The *'Energy-as-a-service' (EaaS)* model provides diversified energy-related services to households such as storing or sharing energy, rather than solely supplying electricity.

The *Feed-in tariff* refers to when households are paid because they generate their own electricity over the use of methods that do not commit to the reduction of natural resources, corresponding to the volume of power generated.

The term *'Photovoltaic (PV)'* describes the type of energy suppliers that offer solar PV systems to private customers.

The *Smart home solution* explains companies that provide households with intelligent lighting, efficient heating, and security systems based on the Internet of Things "IoT", in which these devices can communicate with each other via the Internet.

Energy storage providers are those companies that sell home battery storage systems of different sizes (Vonsien and Madlener, 2018).

Electromobility solution refers to any ancillary services related to electric vehicles (EVs), such as installing charging stations, offering special tariffs for EV owners, etc.

The *Online shop* is a platform that enables companies to sell different products or services via their website.

A *Smart meter* is a device that enables companies to receive actual metered data on electricity consumption.

An *Energy management app* characterizes an interface such as a smartphone app and/or other online platforms that actively enable customers to manage their electricity consumption in real-time.

Demand-side management (DSM) is a technique to enhance the energy framework at the consumption side. It differs from energy efficiency enhancement by utilizing better products, over smart energy costs, incentives for particular consumption approaches, and effective real-time monitoring of distributed energy resources (Palensky and Dietrich, 2011).

Data Analysis for Business Model Canvas

After gathering the information in terms of various existing business models from the company's website, case studies, interviews, etc., we split our main research question into multiple sub-questions in order to answer them according to the building blocks of the BMC (Osterwalder and Pigneur, 2010). Regarding the *Key Partners* building block, companies need to answer the following questions: "Who are our Key Partners? Who are our key suppliers? Which Key Resources are we acquiring from partners?"

In order to point out the companies' *Key Activities* and *Key Resources* building blocks, the following questions need to be addressed: What Key Activities and Resources do the Value Propositions, Distribution Channels, Customer Relationships, and Revenue Streams need?

To complete the *Value Propositions* building block, the customers are entitled to ask the companies the following questions: Which one of the customers' problems do you help to resolve? Which customer requirements do you fulfill? What kind of products and services do you give to each customer group?

The *Customer Relationships* building block answers the questions about: "What type of relationship does each of our Customer Segments expect us to establish and maintain with them? Which ones have we established? How costly are they? How are they integrated with the rest of our business model?"

The *Channels* building block explores how an enterprise communicates with and reaches its customers in order to offer them a Value Proposition and the most important questions are: How is the company reaching its customers now? Which ones are most cost-efficient?

For the *Customer Segments* building block, the following questions are asked: "For whom are we creating value? Who are our most important customers?"

In the *Cost Structures* building block company asks the following questions: "What are the most important costs inherent in our business model? Which Key Resources and Key Activities are most expensive?

To fill in the *Revenue Streams* building block, the following questions were posed: "For what value are customers willing to pay? For what do they currently pay? How are they currently paying? How would they prefer to pay? How much does each Revenue Stream contribute to overall revenues?".

Data Analysis for Business Model Navigator

Although the most successful business model innovation methodologies are the business model canvas and business model patterns, empirical research on the business model canvas's effectiveness for idea creation and group communication, Eppler et al. (2011) find that it can considerably improve collaboration while significantly diminishing creativity. In contrast, the business model navigator does not only promote group cooperation (Gassmann et al., 2014) but also increases creativity by enabling the thinking in analogies (Johnson, 2010). Thus, the identification of the applied patterns and their clustering is carried out according to the business model navigator. Table 4 presents the patterns exploited in the retail electricity market regarding their affected business model components (Gassmann et al., 2013) and created value (Lüdeke-Freund et al., 2018).

Table 4. Identification of the applied patterns, their affected business model components and created value.

Pattern	Description	Affected BM components	Value
Subscription	Through this pattern, the customers pay a fixed charge, typically monthly, to the energy supplier to have access to electricity or other services.	What, How	Economic
Pay-per-use	Through the pay-per-use model, the actual consumption of electricity is metered. The more electricity is used, the more the customer pays. The payment can be a fixed value or differ according to the actual consumption.	What, How, Value	Economic, Social
Open business	Open business model users collaborate with customers and partners to create value. Basically, through the feed-in-tariff scheme, the customers can actively participate in the energy industry by generating electricity and delivering it to the public grid. Moreover, companies collaborate with their partners in order to offer unique solutions.	What, Who, Value	Environmental, Economic
Layer player	It depicts the specialized companies which only generate electricity from owned renewable energy resources and do not operate any non-renewable power plant. These companies mostly benefit from economies of scale, and their established particular expertise – such as renewable power generation – can lead to a higher quality process.	How, Value	Environmental
Direct selling	This pattern describes the firms that generate electricity from their own renewable energy resources and sell it directly to the end consumers.	What, How, Value	Environmental, Economic, Social
Energy solutions	It offers energy-related products and services, such as energy efficiency, optimization, electromobility, and smart home solutions.	What, How	Environmental
Cross-selling	This pattern encourages the companies to advertise various products and services besides supplying electricity. These products typically include solar panels, energy storage systems, smart home equipment, EV charging points, etc.	How, What, Value	Economic, Social
Digitalization	Digitalization in the electricity supply market is made possible by turning energy data into digital variants and monitoring activities through Information and Communications Technology (ICT) and Internet of Things (IoT) solutions. Several technologies, such as solar PV panels, energy storage systems, etc. have the potential to make customers' electricity supply up to 100% self-sufficient. As a result, companies that employ IT solutions and offer energy efficiency and self-sufficiency solutions to residential customers apply the 'Digitalization' business model pattern.	What, How, Value	Environmental, Economic, Social

Within case analysis

Within-case analysis regularly includes detailed case studies investigating reviews for each site. These reviews are typically only simple explanations, but they are critical to the insight creation (Gersick, 1988) since they enable scientists to adapt early in the examination process with the generally large volume of data. There is most likely the same number of methodologies as there are specialists. Although the general concept is to turn into each case as a single element, this process reveals the particular case patterns before researchers apply generalized patterns across cases. Additionally, it provides researchers a complete closeness with each topic and, as a result, helps to pursue cross-case analysis (Eisenhardt, 1989).

Cross-case analysis

A cross-case examination is coupled with within-case analysis for patterns. The strategies here are driven by the fact that individuals are notably weak data processors. Our strategy is to choose dimensions or divisions for cross-case analysis and later search for within-case similarities combined with inter-group diversities. Dimensions can be recommended by the research question or by current literature, or the scientist can pick several dimensions. Generally, the cross-case analysis concept is to push academics forward to go beyond initial impressions, mainly using framed and assorted lenses on the information. These strategies enhance the probability of the precise and dependable hypothesis, a hypothesis with a close match with the information. Cross-case analysis strategies also improve the likelihood that the examiners will capture the innovative discoveries which might be contained in the information available (Eisenhardt, 1989).

2.4 Results

This section presents the results from the interviews and the secondary data collection for within-case and cross-case analysis. Section 4.1 describes the current situation of each company in some detail in Table 5, whereas section 4.2 compares all the companies in terms of their applied business patterns and value creation efforts in Tables 7 and 8.

2.4.1 Within-case analysis

Table 5 presents the results of within-case analysis according to the 'Business Model Canvas' building blocks and Table 6 shows the percentage of revenue invested and acquired from the customer solutions segment.

Table 5. The classification of companies' data according to the 'Business Model Canvas' building blocks.

Company	Organization	Energy Activities	Value Propositions	Channels
E.ON	An international, privately owned energy supplier with more than 5 million private customers in Germany.	Wind, solar, biomass, biogas, and hydropower generation, smart home solutions, e-mobility solutions, operation of virtual electricity saving platform 'E.ON SolarCloud'.	Energy solutions, layer player, Energy-as-a-service, DSM, increasing self-sufficiency, loyalty programs.	Customer portal, app, online chat, cultural and sport events, online store.
innogy	E.ON acquired a 76.8% stake in innogy and made a voluntary public takeover offer for the other shareholders' stock.	Wind, solar, biomass, biogas, and hydropower generation, smart home solutions, e-mobility solutions.	Energy solutions, layer player, DSM, increasing self-sufficiency, loyalty programs.	Customer portal, app, online chat, cultural and sport events, online store.
EDP	One of the largest energy suppliers in Europe, operating mainly in Portugal and Spain.	Hydro, wind, PV, coal, and nuclear power generation, provision of e-mobility services, smart home solutions.	Energy solutions, increasing self-sufficiency, DSM, discount on energy bill.	Customer portal, app, online chat, cultural and sport events, online store.
Vattenfall	One of the largest electricity generators and distributors in Europe, headquarter in Solna, Sweden.	Wind, PV, biomass, coal, and hydropower plants. operating small-scale PV systems and energy storage solutions, provision of energy consulting, smart home services, charging solutions for EVs.	Energy solutions, increasing self-sufficiency, DSM, loyalty programs.	Customer portal and app, cultural and sport events, online store.
Sonnen	Sonnen is a German company which mainly manufactures battery storage systems.	Integration of electricity producers, provision of energy storage systems, smart home services, and e-mobility solutions.	Energy solutions, DSM, Energy-as-a-service, increasing self-sufficiency, loyalty programs, discount on energy bill.	Customer portal, app, and online chat, Sonnen community.
Greenpeace Energy	A first mover in supplying only renewable energies in Germany, Very active contribution to climate and environmental protection.	Wind, solar, and hydropower generation, funding local renewable projects,	Layer player, cutting CO_2 emissions, loyalty programs.	Cultural and sport events, Greenpeace campaign.
Fresh-Energy	A start-up based in Berlin, Germany and operates under an innogy Innovation Hub project and focuses on data management and design.	Analyzing customers' consumption data from smart meters and sends them to the Fresh Energy app. illustration of home appliances energy consumption in real-time	Energy solutions, actual monthly billing.	Customer portal and app.
N-ERGIE	Founded by the Städtische Werke Nürnberg GmbH (StWN) and the Thüga AG in March 2000.	Wind, solar, biomass, biogas, and hydropower local generation, energy saving and e-mobility solutions.	Energy solutions, loyalty programs.	Customer portal, app, and online chat.
Oekostrom	Founded in 1999 to develop a sustainable energy industry in Austria.	Wind, PV, and hydropower local generation, funding local renewable energy projects, operating e-mobility charging stations in Austria.	Layer player, cutting CO_2 emissions, loyalty programs, discount on energy bill.	Customer portal, online store, Oekostrom campaign.
Good Energy	Founded in 1999 in the UK to increase sustainability by supplying and developing renewable energies.	Wind and PV local generation, funding local renewable energy projects,	Layer player, cutting CO_2 emissions, EV electricity tariff, loyalty programs.	Customer portal, cultural and sport events, Good energy campaign.
GridX	A start-up company in Germany, based in Aachen and Munich.	Operation of a virtual power plant, integration of local electricity producers and consumers.	Energy solutions, DSM, actual monthly billing.	Customer portal and app.

Company	Cost structure	Customer-side investments	Energy-side investments	Revenue Streams
E.ON	Cost associated with Key Resources including IT solutions, software technologies, and expert consultants Employees cost (€3.1 m) and consolidation costs (€4.6 m) in 2017.	By investing €595 m in 2017, E.ON's sales from the 'Customer Solutions' sector have been €21.5 m or (56.8% of the total sales). Investment of €637 m in 2018 in 'Customer Solutions', which has increased by 14% in 2019. The planned investment for 2020 will be about €0.9 bn 'Customer Solutions'.	The 'Renewables' segment comprised 1,206 employees in 2017 and has invested €1.2 m in renewables, yet the sales were reported at €1.6 m. Investment of €1.4 m in the 'Energy Networks' segment in 2017, which has achieved sales amounting of €17 m.	'Customer Solutions' segment is responsible for electricity supply and energy solutions. The sales increased by 5% to €23.2 bn in 2019 and accounts for 56% of total revenue (see Table 6).
innogy	Operating expenses of €1.1 m and personnel costs of €3 m in 2017, the charging stations and their installation have roughly cost €7.8 m in total.	€2.81 bn investment in 2017 to achieve 'Customer loyalty index' of 76/100, and a €164 m investment in the retail segment in 2017.	€2.2 m of investment in renewables, grid, and infrastructure segments. €1.8 m investment in the capital expenditure on property, plant, and equipment and on intangible assets.	The 'Retail' segment sales volume of €22.1 bn in 2017 has decreased by 6.8% in 2018 and increased by 1.9% to €21 bn in 2019 (see Table 6).
Sonnen	Costs related to the software, technologies, contracts, and staff (€581,300)	In 2018, Sonnen invested €60 m in developing innovative integrated energy propositions, enhanced EV charging solutions, and grid services based on its virtual battery pool.	Sonnen is building a new production facility in Australia since 2018. Sonnen is benefiting from a new government program in South Australia, which includes AU$ 100 m for up to 50,000 households.	Increased revenues by 50% in the first half of 2018 compared to the same period in 2017.
Greenpeace-Energy	€0.54 m are the costs connected to personnel and intangible assets.	In 2017, the cash flow from investing activities resulted in a cash outflow of €1.55 m, which was slightly above the year 2016. The main driver of this development is the project for the integration of billing services for customers.	It has invested €251.3 m in renewable energy generation units.	The company has gained a higher sales volume, from €101.6 m in 2016 to €110.6 m in 2017 and it remained constant in 2018. Rising customer numbers caused electricity sales to increase from 370 GWh in 2016 to 379 GWh.
Vattenfall	Costs connected to depreciation and amortization e.g., products sold (SEK 13.6 bn, SEK 1 = €0.095), administrative expenses (SEK 1.3 bn), and personnel costs (SEK 18 bn).	In 2017, SEK 7.1 m was dedicated to the 'Customer and Solution' segment. The investment in this segment has increased further in 2018 and 2019 (see Table 6).	SEK 3.4 m to 'Power Generation' and SEK 7.2 m to the 'Wind' segment, the reported cash flow from investing activities has been SEK 18.5 m.	Growth of 120,000 contracts in the German market in 2018. The revenues from the 'Customer and Solution' segment was SEK 78.8 bn in 2017, and has increased by 3% in 2018. In 2019 this revenue raised to SEK 89.8 bn (see Table 6).
N-ERGIE	Costs associated with renewable energy resources.	In the residential segment, the company expects an increase in primary energy consumption and decentralized generation and is going to face this competition by investing in the framework of the digital transformation in order to be more customer-focused.	In 2017, the group invested €112.94 m (2016: €109.3 m). Of this amount, €99.5 m (2016: €101.3 m) was attributable to property, plant, and equipment, €10.29 m (2016: €5.9 m) to financial assets, and €3.1 m (2016: €2.1 m) on intangible assets.	In 2017, revenues from electricity supply remained same as 2016 amounted to €2.14 bn. In 2018, the revenue has increased by 30% to €2.8 bn. In the residential segment, primary energy consumption was expected to increase mainly due to legal requirements and the increasingly decentralized generation in the electricity sector.
Oekostrom	Infrastructure costs e.g., land, buildings, technical equipment, and machinery, etc. (€18.1 m), Administrative costs (€1.1 m), and staff (€2 m).	Against the context of increasingly intensive competition in the end-customer market, Oekostrom has consistently invested in customer loyalty measures in 2017.	The investment amounted to €27.7 m from public funds in technical equipment and machinery in 2017 with a net cash flow of €-8.1 m from its investment activities.	In 2017, Oekostrom recorded an increase in power generation of 80.5 GWh (60.0 GWh in 2016) and total electricity sales of 275 GWh, an increase of 7% compared to 2016. The revenue also increased from €28.7 m in 2017 to €31.5 m in 2018.
EDP	Amortization/impairment of property, plant, and equipment (€1.3 bn), Administrative (€1.4 bn), personnel (€680 m).	In 2017, EDP recorded a total investment of about €2 bn in Portugal alone. For the period between 2016 and 2020, it has achieved 84% of its plan to invest €100 m in social areas.	The investment value in the renewables area has increased significantly from €1.2 bn in 2016 to €1.8 bn in 2017.	A 1% increase in the number of electricity customers in 2017. 'Client Solutions' segment is responsible for electricity supply and energy solutions. The sales increased by 2.8% to €8.64 bn in 2019 and accounts for 49.1% of total revenue (see Table 6).
Good-Energy	Depreciation and amortization costs (£4.2 m, £1 = €1.11), staff (£10.9 m), and administrative costs (£13.1 m).	Allocation of £4 m investment in a customer service platform in order to facilitate an increase in domestic supply, improve customer preservation, and improve overall consumer lifetime value.	Good Energy has invested £41.7 m on the development and building of new generation sites, e.g., wind turbines and solar panel, the net cash flows used in investing activities amounted to £3.8 m in 2018.	In 2017, the total electricity sales increased by 8.5% to 87.6 GWh (80.7 GWh in 2016). In 2017, the sales increased by 16.6% to £104.5 m (£89.7 m in 2016). The total number of customer meters supplied has remained around 115,700 in 2017 and in 2018.

We find that E.ON, innogy, Sonnen, Vattenfall, and EDP are employing the digitalization pattern. Consequently, they could achieve significantly higher revenue in the customer solution segment from 2017 to 2019 due to satisfying more customer needs. We collected detailed data on these companies regarding their percentage of revenue invested in customer solutions, and the percentage of revenue obtained from this segment in Table 6 (note that the Table does not include data on the Sonnen case study due to the unavailability of data).

Table 6. The percentage of revenue invested and acquired from customer solutions segment.

	Investments			Revenue			
Companies	2019	2018	2017	Avg. Revenue from 2017-2019	2019	2018	2017
E.ON	1.74	2.11	1.56	€36.4 bn	56.0 (+5)	73.1 (+2.8)	56.7 (-3.5)
innogy	0.70	0.70	0.44	€38.5 bn	59.3 (+1.9)	55.6 (-6.8)	51.2 (+2.3)
EDP	0.96	3.64	1.10	€17.9 bn	49.1 (+2.8)	46.9 (+7.6)	42.8 (+0.9)
Vattenfall	0.89	0.52	0.44	€15.1 bn	54.0 (+10.4)	53.4 (+3.1)	50.2 (+13.8)

Note: Numbers in parentheses denote percentage of revenue changes in customer solutions compare to the previous year.

Table 6 also presents the percentage of revenue changes compare to the previous years. In order to measure the customer value, we relied on the acquired revenue from the customer solutions and assumed it as an indicator. Our analysis indicates that all the companies, including Sonnen, have experienced a gradual increase in their revenue from the customer solution segments since 2017. In order to respond to the climate targets for 2030 and 2050 in Germany, E.ON investments concentrate on strategic technologies and digital business models that increase its capability to lead the move toward the provision of sustainable, distributed, and innovative energy (services) (E.ON SE, 2020).

According to Table 6, there is significant heterogeneity in the volume of investments and acquired revenue from the customer solution segments. We noticed that there is a positive relationship between the investments in customer solutions and the acquired revenue. Therefore, companies have paid more attention to customer solutions in recent years and increased their investments slightly in this segment. Whereas previous research in the utility business model literature finds that energy companies have been concentrating more on the energy supply side of their business and ignored the customer solutions (Richter, 2013b).

The analysis of the Value Propositions reported in Table 5 suggests that except for Greenpeace Energy, Good Energy, and Oekostrom (the three green incumbents), the other eight companies provide energy solutions – such as reducing energy bills, offering energy management apps, smart home solutions, and EV charging services – of which six companies also offer active demand-side services. However, only the three green incumbents are active in funding local renewable energy projects and mitigating CO_2 emissions through supporting campaigns.

2.4.2 Cross-case analysis

All the case studies are first analyzed according to the existing business patterns in the electricity retail market, products, and other ancillary services related to electricity, and different value creation efforts. The results are presented in Table 7.

Table 7. Business patterns applied by the companies investigated.

Pattern	Value Proposition	E.ON	innogy	EDP	Vattenfall	N-ERGIE	Sonnen	Good En.	Oekostrom	Greenpeace En.	Fresh En.	GridX	Sum
Subscription	Electricity access	X	X	X	X	X	X	X	X	X		X	10
	Flexible contract period						X			X	X	X	4
	Energy-as-a-service	X					X						2
Pay-per-use	Electricity cost	X	X	X	X	X	X	X	X	X	X	X	11
	Actual monthly billing										X	X	2
Open business	Feed-in tariff	X	X	X	X	X	X	X	X			X	9
	Funding local projects							X	X	X			3
Layer player	Renewable generation	X	X					X	X	X			5
Direct selling	Energy	X	X	X	X	X		X	X	X			8
	Hardware						X		X			X	3
Energy solutions	Energy management app	X	X	X	X	X	X				X	X	8
	Smart home solution	X	X	X	X		X					X	6
	EV charge-to-go	X	X	X	X	X	X		X				7
	Low cost energy for EVs	X				X		X	X				4
Cross-selling	PV systems	X	X	X	X	X	X		X			X	8
	Storage systems	X	X	X	X	X	X					X	7
	Smart home products	X	X	X	X		X		X				6
	E-mobility products	X	X	X	X	X	X		X			X	8
Digitalization	Increasing self-sufficiency	X	X	X	X		X						5

Table 7 shows the number of companies offering each Value Proposition (last column). In the following, we describe each of the patterns individually.

Almost all the electricity retail suppliers within this study take up the subscription pattern. Through this pattern, companies charge customers with a monthly regular fixed cost in order to provide them with electricity access. Four companies enable households to have a flexible contract even for a minimum of one month, whereas others oblige customers to sign a contract period for a minimum of 12 months. Energy services, such as 'SolarCloud' and 'SonnenCommunity,' are offered by E.ON and Sonnen, respectively. Based on the subscription pattern, these two companies empower private households with PV systems, converting them to so-called 'prosumers' (Oberst and Madlener, 2015) to store or share their surplus generated electricity with other households.

Over the pay-per-use pattern, customers pay for their electricity consumption. Typically, in the German electricity retail market, utilities do not provide consumers with actual electricity consumption per month. As a result, customers pay a fixed cost for the electricity utilization, which is proportional to the number of family members. Fresh Energy and GridX have innovated around the pay-per-use pattern. It informs the customers about their actual energy consumption data and issues electricity bills accordingly. Therefore, customers pay for what they have consumed within the specified month.

Through an open business model, energy suppliers collaborate with customers and partners to create extra value. Accordingly, the feed-in tariff scheme is the most frequently offered Value Proposition of the companies, followed by the funding of local renewable energy projects. Regarding the layer player pattern, E.ON, innogy, and the three green incumbents generate mainly electricity from owned renewable energy technologies, including wind, solar, and hydropower, and do not operate any non-renewable power plant.

Table 7 also shows that eight companies covered in this study generate renewable electricity from their own assets and directly sell to the end-consumers according to the direct selling pattern. Companies also directly sell additional products such as hardware, lithium-ion batteries or PV systems; energy management systems (Gridbox) are provided by Sonnen, Oekostrom, and GridX, respectively.

Energy management apps that inform consumers about their actual electricity generation and/or consumption are provided by all companies in our sample except for the three green incumbents. Besides, the three green incumbents, N-ERGIE, and Fresh Energy, also do not include smart home solutions in their business models. EV charge-to-go is seen as an essential Value Proposition by seven companies; however, only four of them offer low-cost electricity tariffs for EV owners.

Except for Good Energy, Greenpeace Energy, and Fresh Energy, all the other electricity retailers have applied the cross-selling pattern and provide additional products or services besides electricity in their portfolios. Eight companies in this study provide products such as solar PV systems and domestic EV charging stations, and six companies offer smart home services. However, only the multinational companies and Oekostrom run an online store to advertise such products, as mentioned earlier, and other electric devices to the households.

Of the eight patterns, digitalization stands out as significantly different from the others, and it also forms another cluster among the companies (see Table 6). It demands innovative solutions for improving energy efficiency and self-sufficiency. One of the interviewees mentioned that making the households up to 100% energy self-sufficient and increasing their energy efficiency has attracted household attention considerably.

In order to position the business model patterns from Table 7 according to different Value Propositions, e.g., economic, social, and environmental and find out the heterogeneity between the companies in our study, we apply the method of Lüdeke-Freund et al. (2018) to the sustainability triangle by Kleine and Von Hauff (2009). Figure 2 illustrates the classification on the level of pattern groups and the position of the companies (with numbers and colors) in the triangular view as a platform.

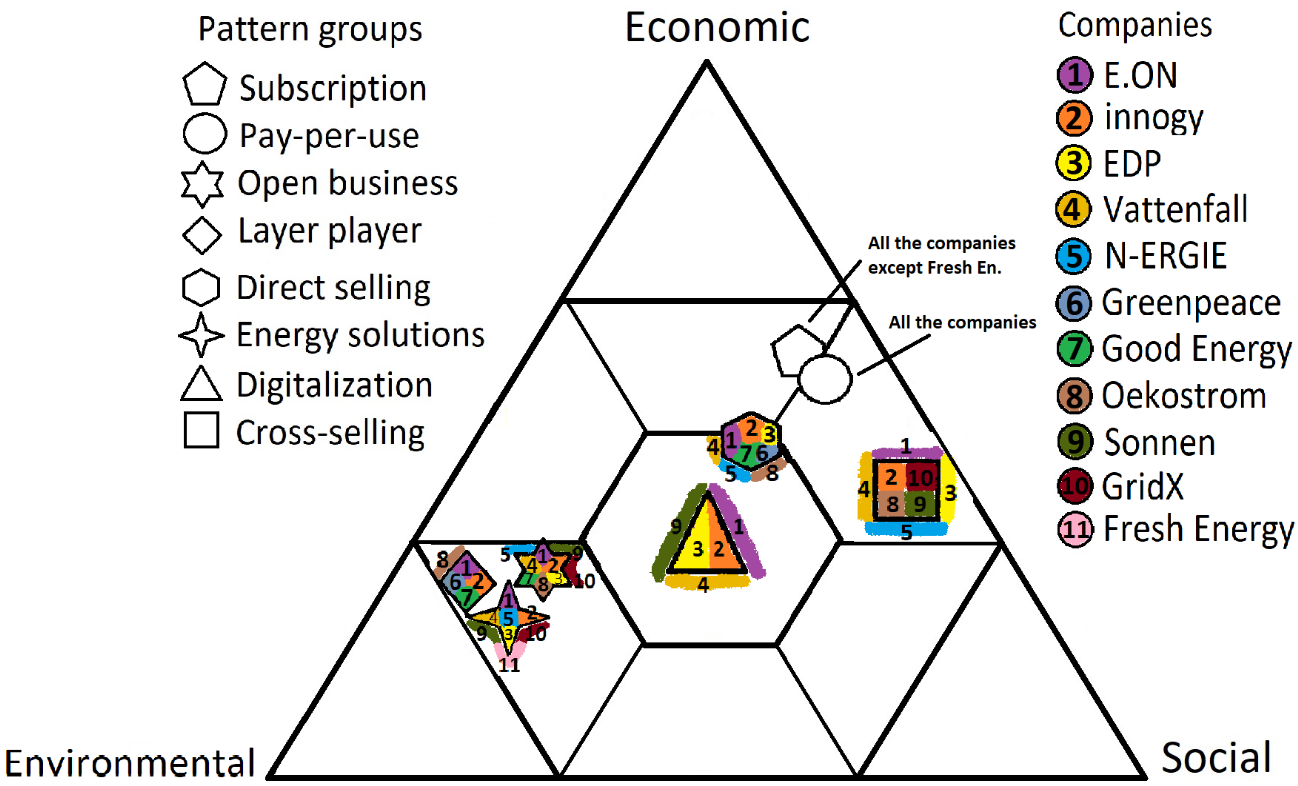

Figure 2. Pattern classification and position of the companies according to the type of value created (sustainability triangle view).

Figure 2 shows that most patterns can directly link to a particular form of value creation. The subscription and pay-per-use patterns are described with mainly as economic value creation, the open business, layer player, and energy solution patterns are mainly environmental, and the cross-selling pattern relates to social-economic value creation. The digitalization pattern is an integrative group that provides equal opportunities to contribute to all three value creation forms. This is also the case for the direct selling pattern, but less clearly articulated and with a tendency towards economic value.

2.5 Discussion

According to a series of interviews conducted with representatives from the companies studied and other sources of data collection, the current study investigates how energy retailers can be more competitive and develop sustainable business models by creating a range of economic, social, and environmental value for private customers in terms of energy efficiency solutions during the energy transition era. Original studies have declared that the growing share of renewable electricity constitutes a threat to the electricity suppliers' business models in their present form (Frantzis et al., 2008; Richter, 2012). Our findings are partly in contradiction with previous research. We can conclude that today's electricity retailers are more consumer-centric according to our three-year' snapshot. They offer different energy-related products and services besides green electricity to their end-consumers through cross-selling and energy solution patterns. These include solar PV, energy storage systems, e-mobility solutions, smart home products and services, and energy management apps.

We find evidence that some of the reviewed electricity suppliers benefit from new technology achievements, such as smart meters and IT solutions. By employing smart meters, companies are able to measure prosumers' actual energy self-supply and consumption in real time and offer them energy management apps. Thus, prosumers are enabled to manage their energy activities in real time. Consequently, the combination of smart meters and IT solutions with solar PV panels, storage systems, energy management apps, and smart home products has enabled the companies analyzed to exploit on digitalization and to satisfy more consumer needs. Researchers emphasize the need to compose the relationship between the social and the technical spheres in order to recognize the contrast "as an accomplishment, rather than something that can be taken for granted." Bijker and Law propose that we should avoid the divisions between "society" and "technology" altogether (Bijker and Law, 1992). Hence, digitalization, as a social and technical pattern has opened up new possibilities in terms of energy management for households and made life easier for them by taking the burden off their shoulders.

Our study shows that all the electricity retailers in the sample have maintained the Customer Relationships and Channels building blocks through common communication patterns, including a personal assistant, social media, website, and press, making life easier for consumers. Other communication Channels, such as customer portals and apps, are frequently employed in several of the investigated cases, whereas only few companies offer online chatting services. Companies may communicate consumer motivations to change behavior through the small portal provided on a smartphone. Engaging the spectrum of communication channels will make an electricity retailer more open, direct, and sympathetic towards its partners. In order to innovate business models, companies need to move with society and the marketplace, which demands supporting customers through the new media landscape (Mueller, 2019).

The most popular business models applied in the retail energy sector include subscription and pay-per-use patterns for renewable electricity. These patterns provide direct impacts on companies' Revenue Streams by generating predictable revenues with lower sale costs. Thus, in the context of renewable electricity subscription, consumers might concentrate heavily on the high and quickly rising financial costs of higher electricity prices, along with the loss of time and effort needed to subscribe when deciding whether to buy renewable electricity. These substantial upfront costs and losses are expected to serve as disincentives to subscribe, mainly where tangible advantages are not quickly apparent (Hobman and Frederiks, 2014). Thus, we suggest the following business model (see Figure 3) to future retail electricity suppliers as an optimal BMC during the sustainable energy transition era.

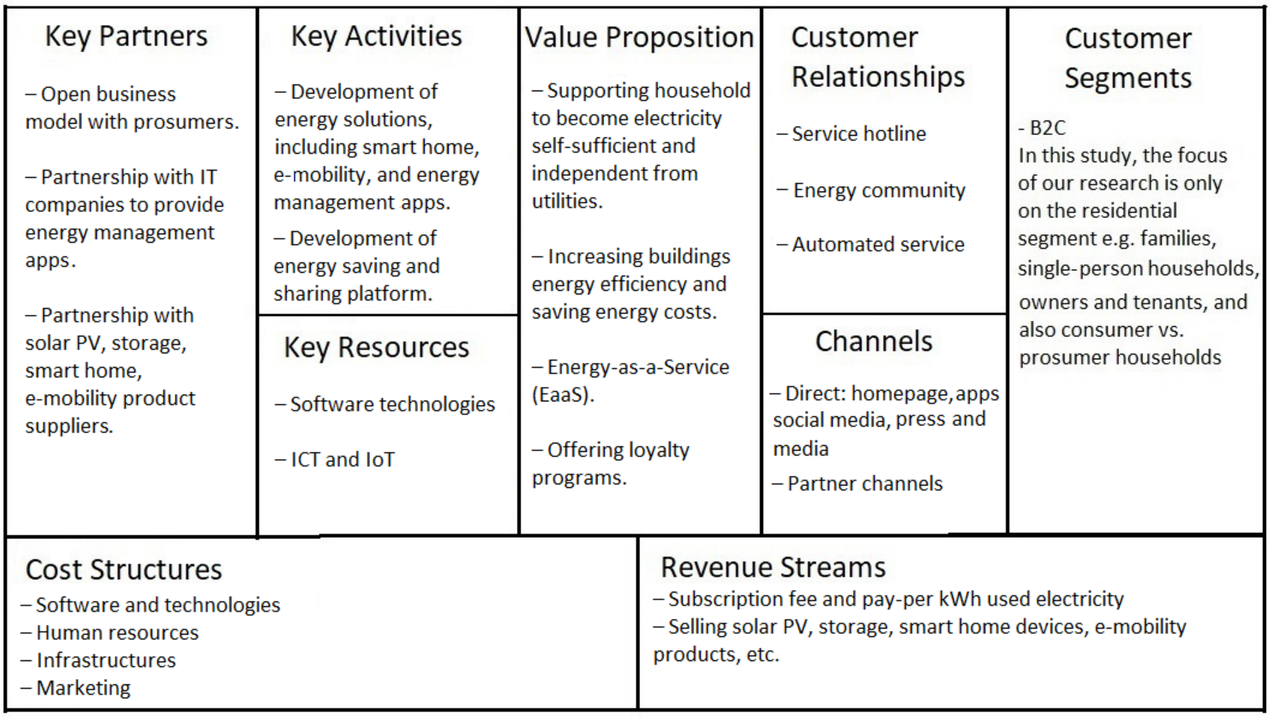

Figure 3. The most optimistic benchmark BMC for future electricity retailers identified.

2.6 Conclusions and implications of the study

The current exploratory empirical research applies the business model canvas and pattern methodology to investigate how retail electricity suppliers have positioned themselves and structured their business models today in order to create economic, social, and environmental value for their private customers. Although our research provides important new insights into the future retailers' position, the conclusions are subject to some limitations.

Firstly, according to our three-year' snapshot, it can be concluded that current electricity retailers take a more consumer-centric perspective for creating extra value. Therefore, besides green electricity, they offer various energy-related products and services – such as solar PV, energy storage systems, e-mobility solutions, smart home products and services, and energy management apps – to their private customers by means of cross-selling and energy solution patterns.

Secondly, the emergence of smart meters and IT solutions has enabled some electricity suppliers to exploit innovative patterns such as digitalization, and to combine these technologies in order to increase the level of households' energy self-sufficiency and make them more independent from utilities. Thus, we expect that still more electricity retailers in the future will add cross-selling, energy solutions and digitalization patterns to their business models, and offer energy services to private customers. These services may include providing energy-sharing platforms among consumers and prosumers within an energy community, operating virtual energy storage pools, and providing demand-side management services.

It can be implicated that business model innovation in the retail electricity market, besides economic values, can create social and environmental values. Luedeke-Freund (2010), considers business model innovation as a solution for fulfilling more comprehensive social and environmental sustainability in the modern system. He describes a sustainable business model as 'a business model that creates competitive advantage through superior customer value and contributes to a sustainable development of the company and society' (Lüdeke-Freund, 2010). Thus, a business model must not be considered as a separate category. Joyce and Paquin (2016) have added social and environmental layers to the BMC. The social layer tries to capture the company's vital social impacts that derive from relationships between stakeholders and the company. Thus it presents a better understanding of where a company's primary social impacts are, and gives insight for investigating ideas to innovate the company's operations and business model to enhance its social value creation potential. The environmental layer's main objective is to appraise how the company generates more environmental benefits than environmental impacts. Thus, it allows users to understand better where the company's most significant environmental impacts lie within the business model, and provides new insights for where the company may concentrate its attention when creating environmentally-oriented innovations.

Companies' managers need to innovate on their business models and offer consumer-centric energy solutions. In order to stay competitive, they have to think beyond the delivery of electricity as a commodity by exploiting new technologies and employing innovative patterns such as digitalization. They should make their business models more expandable by external partners – such as IT companies as well as solar PV, storage system, smart home, and e-mobility suppliers and/or providers. Moreover, companies need to deliver value by performing different activities – such as developing energy solutions and energy sharing platforms – and build their resources based on hard-to-copy resources such as IT, IoT, and software technologies.

The results also have implications for government policy-makers. Since business model innovation is highly subjected to the prevailing regulatory framework, politics can substantially affect sustainable business model development. For instance, new regulations could accelerate smart meter roll-out, which is the key to offering energy management apps and, subsequently, the essence of the digitalization pattern. Moreover, they need to pay more attention to the start-ups and support them to increase market competition and prevent forming a monopoly by incumbents and other large companies.

2.6.1 Limitations and future research

The possibility of interviewing representatives of all of them was not available because the case studies were selected across Europe. The secondary data were mainly gathered from the company's website. Nevertheless, all the information published on their websites and brochures is for informing the customers and stakeholders. As a result, the secondary data is still valid and reasonably accurate. While our research presents general coverage of multinational companies, the situation for the medium-sized, small-sized, and start-up results cannot easily be investigated. Our sample selection is concentrating on the incumbents and pioneers in each cluster. Therefore, this study does not deliver a broad overview of the energy market situation but aims to highlight the most advanced business model innovations and developments. We do not describe the companies' entire business model; our study merely explicates how a company has applied a unique pattern in order to build a more competitive business model.

Since the sustainable energy transition is in progress and requires more research in the field of business model innovation, future research could relate to the business models for the prosumers' households, energy-sharing platforms, and market designs for enabling peer-to-peer (P2P) business models.

Chapter 3

Business Models for Peer-to-Peer Energy Trading in Germany based on Households' Beliefs and Preferences

List of Acronyms

DERs distributed energy resources	**P2P** peer-to-peer	**PV** solar photovoltaic
ETP energy trading platform	**FiT** feed-in-tariff	**TPB** theory of planned behavior
PBC perceived behavioral control	**HH** (private) household	**RES** renewable energy sources
PPA power purchase agreement	**VP** value proposition	**BM** business model

3.1 Introduction

The combination of distributed energy resources (DERs) (Bussar et al., 2016), including rooftop solar photovoltaic (PV) panels, energy storage, and control devices, together with consumer-level communications and control, includes adopting smart meters and energy management systems (Han and Lim, 2010) supporting traditionally passive electricity end-consumers to become 'prosumers' (Toffler, 1980). Energy prosumers are proactive consumers with DERs who actively control their own consumption, generation, and energy storage (Zafar et al., 2018; Oberst and Madlener, 2015). Government-sponsored feed-in-tariff (FiT) schemes or existing electricity retailers with buy-back schemes remunerate prosumers for their excess energy generation fed back into the grid. Nevertheless, as subsidies are reduced and finally phased out, prosumers are being left in a post-subsidy period with no alternative income model for their green surplus electricity (except maybe for marketing green electricity (Herbes and Ramme, 2014)).

There is increasing interest in post-subsidy market models that can offer new value propositions to energy prosumers (Brown et al., 2019; Bryant et al., 2018). Parag and Sovacool (2016) have concentrated on the engagement of more prosumer-oriented electricity markets by introducing three separate possible prosumer integrating market models, namely (1) peer-to-peer (P2P) prosuming models, (2) prosumer-to-grid integration, and (3) prosumer community groups.

Hence, the focus of this paper is on the P2P prosuming market model. P2P markets are the least-structured market models so far and include decentralized, independent, and flexible P2P networks that begin almost entirely from the bottom-up. These markets may also include several long-term or ad-hoc contractual relations among prosuming agents or between another service provider and an energy consumer (Parag and Sovacool, 2016). P2P markets can provide opportunities for all shareholders in the electric power system (Paudel and Beng, 2018; Wilkinson et al., 2020). The presentation of such new markets also creates new business models. One example of such a business model (BM) is the P2P market model (Lavrijssen and Carrillo Parra, 2017; Sousa et al., 2019; Green and Newman, 2017), which in principle enables consumers and prosumers to trade with each other without requiring a utility or retailer as a middleman (broker).

Thus, the middleman is replaced by a third-party digital platform that empowers consumers and prosumers to communicate with each other directly and to bargain more negotiated prices for their electricity rather than relying on the offer from an authorized supplier (Sousa et al., 2019). Platforms are digital places where operators can interact, cooperate, and get permission to access products, services, or other general 'resources' provided by peers or parties. The aim of such a platform is to promote more straightforward connections among people participating in an exchange-based market. They have become a robust economic and technological template model replicated across society, and they are reinforcing trends such as prosumption and digital energy services and technologies (Kloppenburg and Boekelo, 2019).

The existing literature in the field of business models for P2P energy-sharing communities or platforms does not propose business models from households' behavioral points of view and their preferences; little investigation has examined customer decisions in this context so far in Germany. For example, Hackbarth and Löbbe (2020) identified the most promising customer segments and customers' preferences and motivations for participating in peer-to-peer (P2P) electricity trading based on a survey among customers of seven municipal utilities. They find that private households (HHs) with the highest willingness to participate in P2P electricity trading are mainly motivated by the ability to share electricity and – to a lesser extent – by economic reasons. Regarding consumer preferences, Hahnel et al. (2020) investigated energy consumers' and prosumers' willingness to participate in a P2P energy-sharing community. The authors found that community electricity prices and state of charge of private energy storage systems are the main indicators of HHs' trading behavior. While the authors provided new insights into the design of P2P communities, they have not suggested any corresponding business models for HHs that would enable them to engage them in a P2P energy-sharing community.

The international empirical evidence on P2P energy trading business models is still scarce. Studies in South Korea estimate the usage fee for a P2P energy trading platform by determining the willingness-to-pay of possible users (Lee and Cho, 2020) and analyze the economic feasibility of P2P energy trading (Chung, 2020). Studies in the UK present a quantitative analysis of business models at the project level for energy communities (Braunholtz-Speight et al., 2020). Another study for the UK discusses the basic P2P energy-sharing and local community models and elaborates a single case study based on local matching trading (Mujeeb et al., 2019). Lüth et al. (2018) presented the business models that concentrate on the end-user benefits of P2P trade and energy storage, recognizing that the perception of local markets triggers impacts demand response, and changes the interaction with other stakeholders in the electricity market. They implemented an optimization model based on historical demand, generation and price data, in order to analyze the P2P interactions in the presence of storage for a small community in the UK.

Pires Klein et al. (2020) give insights related to P2P energy-sharing business models that will encourage the development of more complex business models for the setting of the Portuguese energy market, regarding and despite its rigorous regulatory restrictions. The authors proposed a business model which resulted in immediate financial benefits due to the collaborative use of the surplus electricity generated from solar PV systems among end-users under the same low and medium-voltage transformer substations. Note that, we argue that an empirical study that offers business models for P2P energy-sharing platforms through responding to households' beliefs and preferences, does not yet exist. In our study, for the first time, we fill this important knowledge gap in the P2P energy trading literature by deriving optimal business models and presenting a German-wide business model analysis of the existing energy communities and platforms. Our findings give a more comprehensive review to researchers focusing on P2P energy trading business models, which is not completely examined in the existing literature. The descriptive methodological and empirical research presented aims at determining how business models for an ideal P2P energy trading platform (ETP) can be designed such that prosumers are motivated to engage with the platform and gain the necessary skills and knowledge to use it effectively and efficiently.

Therefore, the contribution of the current study to the literature is twofold. First, our methodological novelty employs "multiple methods" by combining the Theory of Planned Behavior (TPB) (Ajzen, 1991) in order to analyze household beliefs concerning their attitude, perceived behavioral control (PBC), and subjective norms, and Amit and Zott (2012) business model approach in order to develop optimal business models. We are also using data obtained from an online survey that measures consumers' and prosumers' beliefs and behavior towards energy generation and consumption. Second, our empirical analysis reveals important new insights about business models for P2P energy trading and enables a better understanding of the topic by analyzing and identifying the business models used in fifteen research and industrial projects, and startup companies in Germany which will also be of use for the international scientific community as well.

The remainder of this paper is organized as follows. Section 2 presents the conceptual background and the theoretical frameworks related to the research question. The data and methodology of the current study are outlined in section 3, and the analysis results are presented in section 4. The taxonomy of the proposed business models and their applications follows in section 5. Finally, the conclusion and policy implications of this research are drawn in section 6.

3.2 Conceptual background

P2P trading platforms (see Figure 1) have developed in various divisions, helping small suppliers to compete with incumbents supplying the same goods and services. Whereas vertically combined companies take control of the interactions between producers and consumers, P2P trading platforms enable direct transactions between users, with the users being in control of setting the terms of transactions and delivering goods and services (Hagiu and Wright, 2015). These platforms could present value by enabling prosumers to contract as collaborative organizations while distributing information and uncertainty ("a sharing economy"). It has been proven that groups of wind power generators can grow their corporate benefits by engaging together in wholesale energy markets in order to share risks and benefits due to economies of scale from pooling resources (Baeyens et al., 2013). Thus, prosumers could exchange information with one another, and then more efficiently negotiate as a group with their suppliers.

Hence, P2P ETPs act as a marketplace providing information and matching buyers and sellers. They enable self-regulation of the P2P trading through a platform. The nature of a P2P ETP is not only the creation of a technology or a software package. It demands a systemic method of value creation through facilitating electricity and price negotiations among several interdependent actors in the P2P ecosystem, such as consumers and prosumers. The platform has to afford an efficient and secure marketplace for both buyers and sellers (Pouttu et al., 2017). ETPs utilize a digital interface in order to connect consumers and prosumers. They are designed to connect DERs, either when ownership of assets is decentralized or when spatial dispersal is a solution to the platform's service/s. Thus, digital platforms often do not provide or own physical infrastructures and assets but merely operate as a service provider on top of these. Therefore, they promote decentralized and digitalized exchanges among DERs (Kloppenburg and Boekelo, 2019). According to Mengelkamp et al. (2019a), most business models in local energy markets will be centered around implementing a platform.

Zepter et al. (2019) created a platform for the integration of prosumer communities into intraday and day-ahead market operations. The authors evaluated the potentials of P2P trading and battery storage flexibility in a multi-market system, and developed a two-stage stochastic programming method to demonstrate the various cases of the decision-making process under uncertainty covering possible scenarios on the realization of renewable generation and intraday electricity prices. Their results show a trade-off between wholesale market participation and self-sufficiency of the community. They find that, due to the possibilities of P2P trade and residential household battery storage, power generation from DERs can be utilized locally to a higher extent.

Most existing literature on P2P energy sharing concentrates on residential households, which are typically equipped with solar PV systems. Consequently, most P2P sharing mechanisms are developed considering solar PV systems as the main source of energy in the renewable domain. Thus, solar PV systems have been broadly used in P2P trading to reduce energy costs, reduce peak load, balance supply and demand, and manage network losses (Tushar et al., 2021). For example, Tushar et al. (2020a) proposed an opportunistic energy-sharing mechanism adopting solar PV systems and batteries that support prosumers to decrease their energy costs. In their study, a coalition formation game is designed, which enables a prosumer to compare the benefit of engaging in P2P trading with and without utilizing a battery and, consequently, enables the associated prosumers to form proper social coalition groups in the network in order to manage P2P trading.

Jiang et al. (2020) proposed a multi-leader and multi-follower-based P2P sharing model that reduces the cost of buyers by 4.36%, while improving the benefit of sellers by 12.61% compared to the FiT scheme. Moreover, several other studies (Tushar et al., 2019, 2018) developed a coalitional game-theoretic P2P energy trading approach that requires the prosumers to rely on each other in order to trade electricity. Then, the authors set trading prices through the mid-market rate, according to the prosumers' total available surplus and demand energy. They showed through numerical case studies that their suggested model can always reduce the prosumers' cost of energy in comparison with trading via the FiT scheme.

Indeed, the ultimate objective of P2P trading participants is to address several challenges related to energy trading, including decreasing energy consumption costs, increasing and supporting the sustainable consumption of RES, and increasing the social engagement of prosumers. Studies proposed in the existing literature mainly focus on developing P2P energy-trading mechanisms based on suitable pricing schemes that can enable the participation of a large number of prosumers. Financial transactions are necessary to be securely handled without requiring a third-party administrator. At the same time, trading should lead to the achievement of reducing prosumers' cost of energy, balancing local generation and demand, incentivizing prosumers, and developing pricing mechanisms (Tushar et al., 2020b).

Research on the P2P prosuming model has rapidly progressed over the last years, and three main research lines arise from the earlier literature: (1) business model development, (2) P2P market design, and (3) communication and control engineering. In this study, we concentrate on the business models part. Although the studies into P2P energy trading communities and platforms are still at an early stage, several pilot projects and use cases do already exist. Still, studies in the context of business models for P2P ETPs have contributed to the problem of designing business contracts between different prosumers (Morstyn et al., 2018; Rosen and Madlener, 2016).

Zhang et al. (2018) discuss a business model and a design for an online trading platform called 'Elecbay' during the bidding process. It establishes a four-layer system architecture model for P2P energy trading and presents more results on P2P energy trading benefits. Park and Yong (2017) compared five different P2P energy trading projects based on their business models, including commercialized and pilot services. Their research identified the potential development and coming challenges based on the business model components of each case.

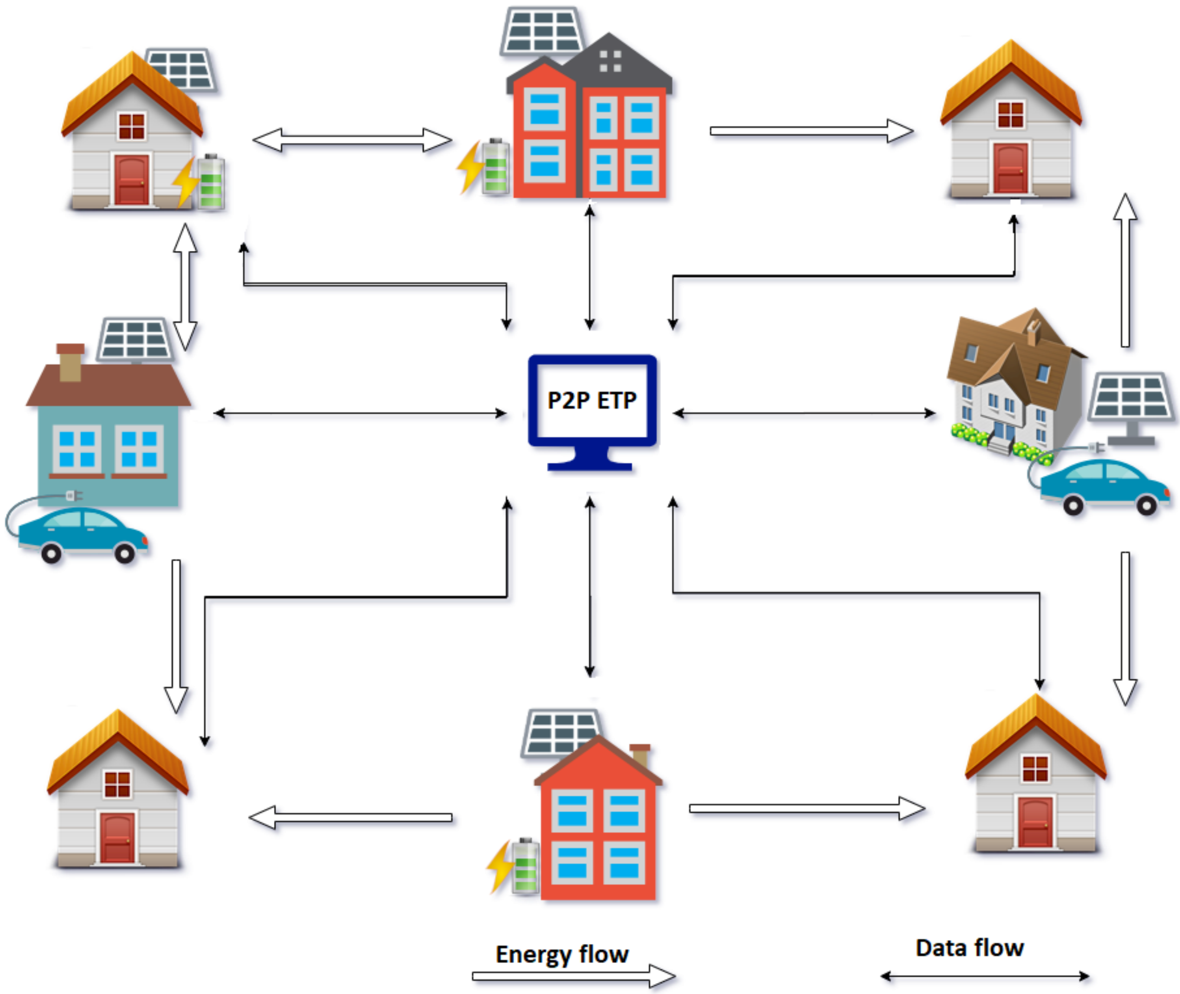

Figure 1. Illustration of a typical P2P energy network among private households.

3.3 Data and methodology

3.3.1 Setting

Our analysis is based on cross-sectional data obtained from an online survey conducted in January 2020 by a specialized market survey company among 3102 HHs living in Germany, which resulted in 1618 polls being available, including 307 prosumers and 1311 energy consumers. The online survey was designed to be answered in approximately 15 minutes and focused on electricity consumption characteristics. In the survey, we aimed to measure consumers' and prosumers' beliefs towards energy generation and consumption. It also focused on the drivers and barriers that consumers experience in the decision-making process, which may influence PV system purchase intentions of the population in Germany (Galvin et al., 2022).

Among the four dominant survey methods, e.g., online, mail, personal, and telephone, we have chosen the online experimental survey. The advantage of online experiments is that they have high internal validity; the negative side is that it may be at the risk of low external validity (Horton et al., 2011). They are also impersonal, often considered to be junk mail, have a low response rate, and have unclear instructions. However, online surveys are fast, have low administration costs, and can include diverse and/or dichotomous questions requiring the completion of answers. They provide convenience for respondents to easily enter their data at any time and also can tailor the survey regarding the respondent's answer (Evans and Mathur, 2005). The use of web-based questionnaires has been a crucial innovation in behavioral science. This approach mixes high efficiency with access to a broader spectrum of participant pools. Via suitable pre-screening, it is likely to target quite distinct groups of people utilizing web-based testing. In our case, an online survey allows separating actual and potential prosumers from consumers who own a house. The following section explains how we have selected the target groups.

3.3.2 Case selection

Our sample consists of HHs who own a house and thus, in contrast to tenants, can decide on energy matters in their HH. Previous research on the openness towards P2P electricity trading (Hackbarth and Löbbe, 2020) has investigated that the respondents' home ownership plays an essential role in participating in P2P energy trading. Thus, respondents were selected to participate in this study on the basis of two selection criteria according to the flowchart depicted in Figure 2.

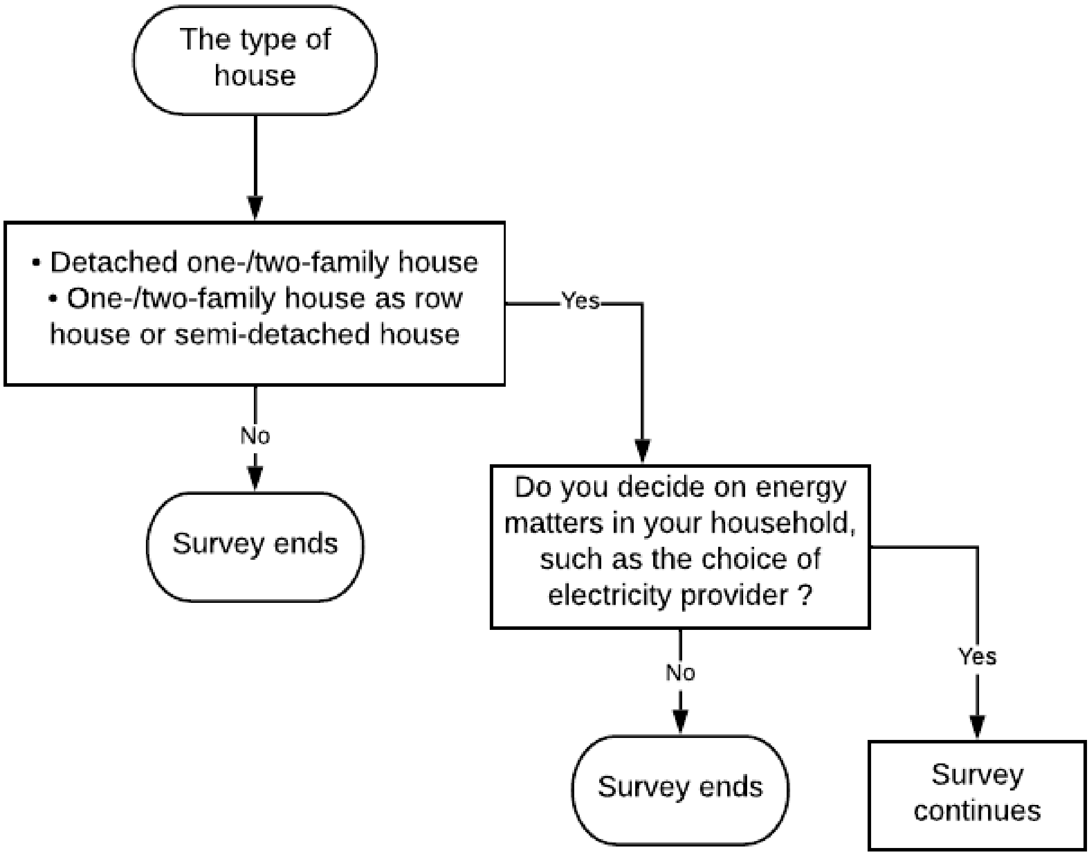

Figure 2. The process of HH selection for participation in the survey.

3.3.3 Data collection

The measured characteristics of HHs and prosumers are energy concern in terms of attitudes and the actions that a respondent takes to conserve energy, pro-environmental self-identity to realize whether the respondents see themselves as environmentally friendly or not, perceived financial situation, and demographics including gender, age, education, and type of HH (see Table 1). The participants' characteristics are measured at the end of the survey. When measuring pro-environmental self-identity and energy concern at the start of the study, this could already put respondents in a certain mindset to make energy-efficient choices. It could also be the case that consumers report having a higher likelihood of buying solar panels than they actually have, creating a bias in the responses.

3.3.4 Data analysis

We have checked histograms and frequencies for all variables to make sure whether any strange values are occurring in the data set. Moreover, we checked response patterns to see whether they were following any response tendencies, such as answers only marked "overall important" even though there are also reversed-coded items. In terms of consistency, respondents should answer "overall not important" instead of "overall important" on reversed-coded items. For respondents who seem to have a response tendency, the individual responses on all other variables and the completion time are checked. For each case, a decision needs to be made as to whether the respondent is a person who will provide final answers or who is not serious. Respondents who have final answers can remain in the data set, whereas non-serious respondents cannot. Thus the additional deletion of data sets regarding other quality control criteria, such as response time and missing values, has been carried out. The summary of the socio-demographic make-up of the total sample based on gender, age, and education-level characteristics for HHs is reported in Table 1. As comparative statistics for the population of household customers in the energy sector are usually not accessible, we examine our survey data against the German population statistics (Table 1).

Table 1. The demographic characteristics of the 1618 HHs surveyed.

Characteristic	Group	Sample	Ratio [%]	Population [%]
Gender	Female	610	37.6	50.6
	Male	1008	62.2	49.4
Age (years)	26-39	172	10.6	18.0
	40-49	228	17.8	12.0
	50-59	468	28.9	15.0
	60-69	440	27.2	13.0
	above 70	250	15.6	16.0
Education	Secondary school certificate	493	30.6	29.6
	Higher education entrance qualification	266	16.5	31.9
	Degree from a technical college	290	18.1	47.5
	University (of applied sciences) degree	560	34.7	17.6
Household disposable income per month	Less than €1500	124	7.6	17.8
	€1500 to €2500	287	17.7	25.3
	€2500 to €3500	395	24.4	17.8
	€3500 to €5000	482	29.8	16.9
	Above €5000	209	12.9	22.2
	Not stated	121	7.5	-
Type of house	Detached one/two-family	1118	69.1	-
	One-/two family	500	30.9	35.2
Role of HH	Prosumer	307	19	-
	Consumer	1311	81	-

In our descriptive methodological study, we apply the methodological triangulation (Denzin, 2017) as our primary form of novelty by combining Ajzen's TPB (Ajzen, 1991) together with the business model concept from Amit and Zott (2012). Methodological triangulation explains the use of multiple methods in order to observe a given social phenomenon in multiple perspectives (Denzin, 2017). Effective implementation of multiple methods ("mixed methods approach") can bring more sophisticated answers to research questions, and help overcome the limitations of individual research approaches (Flick, 2011). According to the TPB, consumers may have several beliefs that shape their attitudes and perceived behavioral control and social norms. It presents a model for foretelling human behavior while implying that intention defines the behavior and is based on the assumption that behavioral intention belongs to three prominent circumstances: attitudes towards the behavior, social pressure to enact the behavior (subjective norms), and perceived behavioral control (PBC) for performing the behavior. In order to respond to the HHs' beliefs, we are developing business models according to Amit and Zott's approach, and configure our proposed P2P ETP by subdividing our main research question into the following six research questions:

(1) What consumer demands will the new business model serve?

(2) What unique actions could help meet those demands?

(3) How could the actions be combined in unique styles?

(4) Who should conduct the actions and what unique governance organizations can we discover?

(5) How will economic, social, technological, and environmental value be created for every partner?

(6) What revenue streams can be adjusted to complement the business model?

Therefore, the current study's objective is to develop business models that can motivate prosumers to participate in a P2P ETP by describing the characteristics of the data. The collected data from employing our online survey include relevant measures for intention, e.g., attitude, subjective norm, and PBC under the TPB model. As an attitude, we measure the perceptions of the authenticity and effectiveness of PV systems and expectations in terms of cost savings and generating revenues. We measure the affinity with technology and awareness regarding saving energy vis-a-vis participants' perceived behavioral control. The first one explains the degree to which participants perceive that they have some knowledge of and like technology, while the second describes how participants think that they know enough about saving energy and jointly controlling their energy consumption. Concerning subjective norms, we include the descriptive and injunctive norms established by close peers; for example, whether many neighbors, colleagues, and family members have PV systems and helped participants to acquire them. Thus, our research describes the data characteristics, including means and proportions.

To identify the main drivers for prosumers, they were asked to indicate the importance of and their agreement with several statements that eventually made them decide. We also analyzed the reasons which prevented the consumers from buying PV systems, evaluated by the correctness of those barriers. Table 2 shows the response of prosumers' motivations and consumers' obstacles towards purchasing solar PV systems. The definitions in Table 2 are categorized according to the TPB and explained in more detail in the following results section.

Table 2. Variables used in the survey.

Components	Definition	Mean (Min =1, Max =4)	Standard deviation	Ratio [%]
Prosumers' motivations towards purchasing solar PV systems	Savings/financial incentives	3.45	0.040	93.4
	Independence from utilities	3.10	0.053	74.2
	Climate protection/ecological reasons	3.07	0.058	73.9
	Interest in new technologies	2.99	0.051	76.8
	Influence of friends and relatives	1.80	0.057	25.1
	Legal obligation of the local authority	1.53	0.056	15.9
Prosumers' behavior towards energy use	Good feeling towards consuming self-generated electricity	3.24	0.056	85.1
	Becoming more aware of their own energy consumption	2.94	0.055	74.6
	Paying more attention to using energy economically	2.92	0.056	73.2
	Interest in sustainable energy transition	2.84	0.063	68.7
	Being aware of the source of consumed electricity	2.72	0.065	60.0
	Trying to consume the generated electricity completely	2.38	0.066	45.5
	Ignoring the volume of consumed electricity	1.97	0.057	29.3
	Ignoring the purchase of energy-efficient home appliances	1.68	0.058	21.5
Consumers' obstacles towards purchasing solar PV systems	Financial reasons	2.75	0.032	64.2
	Technical or structural reasons	2.56	0.032	56.1
	Unclear legal framework	2.04	0.029	33.5
	Lack of interest in solar PV systems	1.84	0.029	25.9

3.4 Results

3.4.1 Households' electricity data

For the data analysis, we have categorized the HHs' annual energy consumption into four different groups in 2000 kWh steps, because this makes the data analysis easier for HHs and gives a clear insight into their energy consumption. We perform this analysis using a data set on the behavioral characteristics of HHs, collected from our survey undertaken in Germany. Table 3 presents the taxonomy of HHs in terms of their annual electricity consumption and incurred costs in 2018.

Table 3. Classification of HHs according to their annual electricity consumption and incurred costs in 2018.

Electricity consumption	Electricity consumption [kWh p.a.]	Ratio [%]	Electricity cost [€ p.a.]	Ratio [%]
Low and very low	0-2000 (349)	21.5	0-600 (311)	20.7
Normal	2001-4000 (845)	52.3	601-1200 (810)	54.0
High	4001-6000 (276)	17.0	1201-1800 (270)	18.0
Very high	above 6000 (148)	9.2	above 1800 (110)	7.3
Total number of HHs in sample	(1618)	100	(1501)	100

Note: The numbers in parentheses represent the number of HHs in each category.

As reported in Table 3, 52.2% of the HHs have an electricity consumption level of between 2000-4000 kWh per year. The average volume of electricity consumed in Germany is 3501 kWh, and the mean cost of electricity is €1044 per year. The cost of residential electricity for HHs is given in €600 steps. This classification is selected because the price of the electricity for the residential sector in Germany, according to the Agency for the Cooperation of Energy Regulators (ACER) Market Monitoring Report in 2018 (for the Cooperation of Energy Regulators , ACER), was 29.9 €-ct/kWh. Therefore, every 2000 kWh of electricity will cost almost €600 on average. Regarding the type of electricity tariff, of the 1380 respondents, almost 20% are supplied with electricity from 100% renewable energy resources. The rest have electricity produced from a mixture of renewable and non-renewable energy resources.

Of the 1618 respondents, 307 HHs are equipped with solar PV systems. Table 4 shows the prosumer HHs' data regarding PV system capacity, feed-in volume, self-supply, and remuneration cost with their mean values.

Table 4. Two different prosumer groups according to their PV system capacity, feed-in volume, self-supply, and remuneration in 2018.

Variable	PV capacity [kWp]	Feed-in volume [kWh]	Self-supply [kWh]	Remuneration [€ p.a.]
Small prosumers	0.1 - 9.9 (162)	0 - 5000 (114)	0 - 1500 (31)	0 - 1000 (108)
Mean/standard dev.	5.9/0.19	2478/136.9	849.6/72.5	480.5/28.4
Total	957.6	282,576	26,339	51,892
Large prosumers	above 9.9 (82)	above 5000 (81)	above 1500 (36)	above 1000 (98)
Mean/standard dev.	N.A.	8378/579	3753/672.5	2715/132
Total	N.A.	678,621	135,124	266,107
Sum of prosumers	(244)	(195)	(67)	(206)

Note: The numbers in parentheses represent the number of prosumers in each category.

Aside from the substantial heterogeneity in the size of solar PV systems above the 10 kWp capacity limit, we find that other summary statistics are more homogeneous with acceptable standard deviations. However, large prosumers could feed-in a higher volume of electricity and generate significantly higher revenues than small prosumers could. Out of 307 prosumers in the survey, 211 use their solar PV systems to generate electricity for their supply, whereas the remainder acts mainly as electricity suppliers and generate revenues through FiTs and sales to energy companies (direct marketing). Thus, only data from 67 prosumers regarding their self-supply volumes are presented in Table 4.

3.4.2 Households' beliefs towards energy

According to the TPB (Ajzen, 1991) and research in the field of energy (Liu et al., 2020), attitudes towards a particular behavior or product are a significant predictor of behavioral intention.

Attitudes

Our survey focuses on the attitude of consumers and prosumers in terms of costs and benefits. The results provide a general picture of prosumers' experiences and attitudes, which can help to better understand the financial and non-financial drivers for becoming a prosumer.

- **Costs: high initial costs, long payback period, lack of funding**

Cost/benefit beliefs can influence people's attitudes towards purchasing solar PV panels (Ajzen, 1991). It emerged that cost savings and financial incentives were by far the most frequently mentioned consideration, with average values greater than 2 ('average importance') for purchasing PV systems. Of the 307 prosumers in our survey, 287 purchased a PV system after buying their houses, 156 considered the cost of PV systems to be very important, and 112 believed costs were an important reason. Therefore, 93.4% (mean: 3.45) care about financial factors.

Out of 1311 HHs, 87 were planning to implement a PV installation in the near future. Moreover, 835 of them (almost 63%) have already thought about installing a PV system on the rooftop of their houses. They believe that due to financial reasons, they could not afford to buy a PV system (mean: 2.75). Therefore, the cost issues are an especially dominant barrier to the consumer group for becoming prosumers.

- **Benefits: reliability, effectiveness, saving, and earning money**

Households decide to become prosumers in order to generate enough energy and to save on energy costs. They received a question regarding whether they want to become self-sufficient and to consume less electricity from the public grid, and more specifically, whether they want to become independent from utilities. The result shows that this was the second-most important reason for purchasing PV systems. Out of 287 prosumers, 119 considered it to be very important, and 94 found independence from electricity suppliers to be an important motivation, which accounts for 74.2% (mean: 3.10) of the group of prosumers. Only 15% of the prosumers did not care about the self-generation feeling, whereas the rest (85%) had a positive experience (mean: 3.24).

When asking the 307 prosumers about consuming energy economically, 73.2% (mean: 2.92) mentioned that, since they are generating electricity by themselves, they pay more attention to using it economically. Accordingly, 45.5% (mean: 2.38) of the prosumers declared that if their self-consumption is lower than the amount of electricity produced, they change their behavior to consume the self-produced electricity as fully as possible. Moreover, being self-sufficient has informed 60% (mean: 2.72) of the prosumers in terms of the source of their consumed energy, whether it is self-generated or drawn from the public grid, and has raised their interest in the development of the sustainable energy transition in Germany.

Perceived behavioral control

For examining the respondents' perceived behavioral control, we measured the following beliefs:

• Affinity with technology: the extent to which HHs perceive that they possess knowledge of and like technology.

• Knowledge of energy-saving and efficiency: the extent to which HHs think they know much about saving energy and closely monitor their energy consumption.

The higher a consumer has perceived behavioral control, the higher the consumer's intention to participate in a P2P ETP will be. For example, if a consumer believes that they can understand all the technical information provided about solar panels and P2P energy trading, the probability that they will purchase them and participate in such a platform is higher.

• **Affinity with technology**

Interest in technological issues and having a more than average knowledge of technology can encourage people to seek out that technology. When we asked about having an interest in new technologies, out of 287 prosumers over three-quarters of them (mean: 2.99) mentioned that they had already purchased a PV system due to their enthusiasm for PV technology.

• **Knowledge of energy saving**

When looking at prosumers' behavior towards energy saving and energy efficiency, it emerged that not all 307 prosumers are necessarily experts in this field. Still, 29.3% (mean: 1.97) mentioned being impassionate about energy consumption and ignoring the volume of consumed electricity, and only 21.5% (mean: 1.68) ignored the potential purchase of energy-efficient home appliances. Additionally, 74.6% (mean: 2.94) indicated that they had become more aware of their self-generated electricity consumption.

The two supplementary Tables 5 and 6 show the impact of HHs' net income and education on the interest in solar PV technology and knowledge of energy savings and energy efficiency.

Table 5. Impact of households' net income on the interest in solar PV technology and knowledge of energy savings and energy efficiency

Components	Income below 3500 EUR		Income above 3500 EUR	
	Mean	Standard dev.	Mean	Standard dev.
Interest in solar PV technology	2.95 (112)	0.085	3.01 (151)	0.071
Being passionate about energy consumption	3.09 (119)	0.089	2.85 (159)	0.085
Ignoring the purchase of energy-efficient home appliances	1.67 (119)	0.089	1.65 (160)	0.081
Becoming more aware of self-generated electricity consumption	2.98 (120)	0.082	2.89 (162)	0.076

Note: The numbers in parentheses represent the number of prosumers in each category.

Table 6. Impact of households' education on the interest in solar PV technology and knowledge of energy savings and energy efficiency

Components	Without university degree		With university degree	
	Mean	Standard dev.	Mean	Standard dev.
Interest in solar PV technology	2.99 (173)	0.065	2.95 (114)	0.086
Being passionate about energy consumption	2.98 (181)	0.078	2.95 (121)	0.091
Ignoring the purchase of energy-efficient home appliances	1.62 (183)	0.073	1.68 (120)	0.088
Becoming more aware of self-generated electricity consumption	2.92 (184)	0.070	2.87 (122)	0.087

Note: The numbers in parentheses represent the number of prosumers in each category.

It can be seen that, unlike the minor impact of education (see Table 6) on the interest in solar PV technology and knowledge of energy savings and energy efficiency, HHs' net income (see Table 5) plays an important role. This is evident when HHs with a net income lower than 3500 EUR per month are more passionate about energy consumption than the other groups with higher disposable incomes per month. Moreover, HHs with lower incomes are more aware of their self-generated electricity consumption.

- **General perceived influence**

Perceived influence on the environment may influence consumers' perceived control. At the top of the non-financial motivators, climate protection also ranked high, only second to the top driver, i.e., independence from electricity suppliers. Of those 287 prosumers who purchased the PV system after buying their houses, almost three-quarters (mean: 3.07) indicated that they care about climate protection and about contributing to a better environment.

- **Specific perceived influence**

The analysis focuses on the barriers consumers may face, especially during decision-making about purchase solar panels. Technical and building issues have influenced 56.1% (mean: 2.56) of the consumers as important barriers. These problems are mainly reported as roof-related problems, monument protection, and existing trees near the houses.

About 20% of the consumers indicated that problems such as difficulties in implementing the PV systems, or the perceived inability to find an appropriate skilled craftsperson, are their primary concerns. Also, due to the anxiety about fire, 14% of the respondents mentioned that they refused to install a PV system.

Subjective norms

Normative beliefs are affected by the likelihood that important peers or organizations will support or oppose a behavior (Ajzen, 1991). Normative beliefs foresee a perceived social norm (e.g., perceived social pressure to show or not to show a particular behavior). The study suggests that consumers are influenced by (subjective) social norms for judgments regarding energy utilization (Weber, 1997; Painuly, 2001).

In the context of solar panels, a consumer's decision (not) to buy a solar panel might be influenced by people who are close in terms of physical proximity (neighbors and colleagues), and people who are close in terms of emotional proximity (family/friends). The more that purchasing solar panels is perceived as the social norm, the higher the consumer's purchase intention. For example, if a consumer is encouraged by friends and family members to purchase solar panels, that consumer is more likely to purchase them. In order to analyze the subjective norms, we measure the descriptive and injunctive norms set by close others, for instance, whether many neighbors, friends, and family members have solar panels and thus (actively or passively) encourage the respondent to also purchase solar panels.

- **Descriptive and injunctive norms through neighbors, friends, and family**

Consumers may have perceptions regarding which behavior is typically performed by these important peers (descriptive norm). For example, if many important peers have solar panels, the typical behavior among them is to purchase solar panels. The consumer may perceive that purchasing solar panels is the norm, thus increasing the consumer's intention to buy solar panels. However, prosumers who choose solar PV because of the influence of friends, relatives, and neighbors were among the lowest proportion of the technology installers (mean: 1.80).

3.5 Taxonomy of the proposed business models and their applications

Next, we want to better understand how business models can help P2P ETPs to create a range of economic, technological, social, and environmental values for different groups of HHs in terms of attitude, perceived behavioral control, and subjective norms. The proposed business models would categorize the HHs, similarly to Table 4, into two different groups, including the consumers, depending on the type of energy activity undertaken (generation versus consumption), installed capacity, and trading volume (feed-in versus consumed), self-supply, and remuneration costs. For designing a P2P energy trading scheme, it is assumed that several consumers and prosumers with rooftop PV systems (without batteries) are connected to a P2P ETP. The prosumers are connected through a secure information system via their smart meters for all required communication and P2P trading transactions.

3.5.1 BM 1: Business models for attitudes

BM 1.1: High initial costs, lack of funding:

As mentioned above, almost 64.2% of the consumers have already considered the installation of a PV system in their houses. However, due to financial reasons, they could not afford to buy a PV system. Therefore, the cost issues are an especially dominant barrier for the consumer group to becoming a prosumer. Energy service providers can tackle this problem by adopting consumers through a leasing model. Consumers can be financed and rent PV systems instead of paying substantial upfront costs. This business model can guarantee to the provider a long cooperation with HHs with base-load generation. Moreover, operators can offer additional services, such as planning, installation, and regular maintenance, in order to generate some marginal revenues for themselves. So far, a few German utilities, such as Sonnen[1], have added a PV leasing business model to their portfolio.

BM 1.2: Saving and earning money:

We find that almost all the prosumers in our survey are relying on revenues through the FiT scheme, and only a few are registered in a P2P ETP or other energy-sharing communities. However, after removing the FiT scheme, only a small group of prosumers can create a financial surplus. The baseline projections assume that existing financial support regarding self-generation and FiT over the period to 2020 will be discontinued. Therefore, prosumers who want to generate revenue may sign a contract with utilities as intermediators or join an energy-sharing platform to sell and share their surplus electricity and, consequently, to achieve financial benefits. For these groups of prosumers, we recommend that energy service providers exploit one or more of the following six business models:

[1] https://www.sonnen.de/

BM 1.2.1: Power purchase agreement (PPA), auction, and bilateral-based contracts:

Several studies propose auction-based and bilateral contract-based P2P electricity trading in which platform operators can enable consumers and prosumers to trade energy based on their bid and ask prices (Liu et al., 2019; Khorasany et al., 2019; Li and Ma, 2020) and operate as something like an 'Energy-eBay' (Rosen and Madlener, 2016). For instance, real-world platforms, such as Lition Energie[2] and Enyway[3], are operating based on the bilateral contracts and blockchain-based online marketplaces for energy in Germany. However, the PPA business model can guarantee prosumers an extended revenue stream, and thus P2P ETP operators can increase their predictability through a low-cost transaction trade (buy once and sell recurrently) and provide the base-load for the other customers. With this model, on the one hand, a bid which is higher than the utilities' bids can be submitted (utilities consider this surplus electricity as non-dispatchable and, therefore, are typically not willing to offer high bids); on the other hand, this bid must be lower than the retail ask price to be sufficiently attractive for P2P ETP operators' arbitrage.

BM 1.2.2: Free energy up to a certain percentage of the feed-in volume:

Small prosumers can be provided with free-of-charge services and electricity corresponding to their surplus volume of electricity that they have already fed into the community platform. In the long run, it can save the cost of purchasing electricity and create financial benefits especially for prosumers with higher energy generation capacities and lower consumption rates. As a real-world example, Sonnen (GmbH, 2020) offers this business model and enables prosumers to feed in their excess solar power into the grid and share it with other members of the energy community. In return, prosumers will receive an individualized volume of free electricity that they can consume on less sunny days.

BM 1.2.3: Self-supplied electricity, and contributing to a virtual battery provider:

With this business model, small prosumers are enabled to save their surplus energy in a virtual account and consume it whenever they want. Being electricity self-sufficient and independent from utilities is stated as the second-most important reason from a HH's point of view for purchasing PV systems. Moreover, prosumers get a good feeling when they consume electricity that has been generated by themselves. Therefore, P2P ETP operators can help HHs to become more electricity self-sufficient and to deliver some extra value proposition (VP). In this regard, E.ON SolarCloud[4] and SENEC.Cloud[5] operate as virtual electricity accounts and let prosumers store their surplus electricity in virtual batteries. Thus, prosumers can consume the stored electricity in their virtual accounts whenever they need it and become more independent and self-sufficient. The motivation to increase electricity self-sufficiency from

[2] https://www.lition.de/

[3] https://www.enyway.com/

[4] https://www.eon.de/

[5] https://www.senec.com/

energy suppliers could result in a more positive attitude towards participating in P2P electricity trading among the HHs (Hackbarth and Löbbe, 2020) since they have the potential to increase the degree of self-sufficiency (Hahnel et al., 2020).

BM 1.2.4: Sharing energy with friends: P2P ETP can bring a community of small prosumers and consumers together in a platform by forming a private P2P network and enabling them to select their energy trading partners specifically to share their surplus electricity with them. This business model can save the cost of energy for the prosumers within an energy community, and since they share their surplus generation, a higher energy self-consumption can be achieved. For instance, through the SENEC.Cloud, prosumers are able to share their electricity with two other HHs located in Germany. Hackbarth and Löbbe (2020) state that HHs who consider sharing generation and consumption to be a critical factor, are more expected to participate in a P2P ETP.

BM 1.2.5: Subsidized business model: A P2P ETP may offer several VPs for free or at very low prices to prosumers and consumers by being cross-subsidized through reliable revenue streams. The "Virtual Power Plant" is the name of a research project of the University of Wuppertal in Germany, which belongs to the local energy utility WSW and has been a registered non-profit organization since 2017. It aims to investigate the local urban energy supply and flexibility of HHs with demand response via incentive signals, which represent energy inadequacy and surplus based on market prices and local generation data[6].

BM 1.2.6: Donation business model: Prosumers may donate their surplus electricity to low-income consumers. This business model based on altruistic behavior can be implemented to counteract fuel poverty or to support the low-income groups of society and to create social and economic values for them. The Brooklyn Microgrid P2P ETP project (Mengelkamp et al., 2018a), as a real-world example, has enabled philanthropic prosumers to donate electricity to low-income HHs.

3.5.2 BM 2: Business models for perceived behavioral control

BM 2.1: Affinity with technology

In order to respond to the technological interest of HHs, P2P energy trading should be oriented as a tech-based VP with a low-cost structure that may operate based on blockchain technology or other technological novelties for creating a communication channel via the platform. According to Mengelkamp et al. (2019a), most business models in local energy markets are focused on presenting a platform or process management. Thus, an easy-to-use platform needs to be designed, which can integrate HHs in order to create new VPs in well-being, convenience, economic growth, and societal impacts.

[6]https://www.evt.uni-wuppertal.de/forschung/forschungsgruppe-betriebskonzepte-und-sektorenkopplung/vpp-virtual-power-plant.html

Regarding knowledge of energy-saving and efficiency, P2P ETPs need to provide prosumer services which enable them to carefully monitor their energy generation, consumption, load profile, trading transactions, energy savings, and efficiency measures. Reuter and Loock (2017), Mengelkamp et al. (2018b), and Hahnel et al. (2020), state that interest in technological applications is a critical determinant for participation in local energy markets.

BM 2.2: General perceived influence

In order to create environmental value, P2P ETPs must only integrate renewable energy sources inside the portfolio in order to decrease emissions and avoid non-renewable power generation. This can also provide social VPs and help to form a community of members with shared climate protection concerns. According to Hackbarth and Löbbe (2020), the respondents' attitudes towards the environment are one of the largest predictors of openness towards P2P electricity trading.

BM 2.3: Specific perceived influence

Technical and building issues, including roof-related problems, monument protection, and existing trees near the houses, difficulties in implementing the PV systems, or the perceived inability to find an appropriately skilled craftsperson were indicated as some of the main concerns for consumers who have resisted buying a PV system. In order to tackle all these problems and provide consumers with self-generation, P2P energy traders can invest in partners' renewable power plants on behalf of consumers, as e.g. in the form of stocks or bonds, and supply them with the energy generated from their invested assets. For example, Enyway enables consumers with the issues mentioned above to invest in its solar systems and become electricity self-sufficient even as a tenant without owning a roof, or an insufficient budget.

3.5.3 BM 3: Business model for subjective norms

As a quarter of the prosumers were found to be influenced by friends, relatives, and neighbors in the decision about installing solar PV systems, P2P operators can use this peer-based marketing channel as an opportunity and offer a friend referral bonus. On the one hand, this channel will create a business opportunity for both prosumers and consumers to trade electricity via the P2P ETP. On the other hand, it can also help the participants to gain status and to generate more revenue, a powerful incentive to increase the market share of a P2P ETP. Lition Energie has added friends referral bonus to its business model and offers incentives to HHs that invite others to join the energy platform. Additionally, peer outcomes – i.e., relying on friends and family as the primary sources of information for energy-related topics – reveal a more positive attitude towards participating in P2P electricity trading within the HHs

(Hackbarth and Löbbe, 2020; Palm, 2017).

3.5.4 Case study analysis

In order to examine the developed business models' validity and applicability further, which are summarized in Table 7, we apply them to the fifteen pioneer existing energy communities and platforms (see Table 8), including eleven companies and four research projects in Germany. The case studies' data are collected from their websites from January to February 2021 and are briefly introduced in the Appendix. Using qualitative methods, we characterize these fifteen ETPs and project business models systematically. Thus, we offer a package of business models that can be utilized in future projects' perspectives.

According to Tables 7 and 8, both the packages of business models and taxonomy fill an essential gap in the ETP literature by providing a Germany-wide analysis of different financing mechanisms for energy platform and community projects, HHs' needs, and value propositions. We find that there is a considerable difference in the number of applied business models offered by the cases. Of the fifteen case studies, the majority (twelve) are integrating RES (BM 2.2), in which nine projects offer smart contracts in the form of an 'Energy-eBay' platform (BM 1.2.1), thus enabling HHs to sign a contract with their favorite energy supplier. Among these use cases, eight exploit blockchain technology in their business models for creating communication channels between the prosumers and consumers within the ETP (BM 2.1). Other remaining projects use different technologies, such as Cloud solutions, Software-as-a-Service, Platform-as-a-Service, etc., in order to create a communication channel. Concerning the energy cost-saving business model (BM 1.2.2), the LAMP and SonnenFlat case studies enable HHs to receive free electricity under some circumstances.

Since most of the ETPs and projects belong to newly established start-ups, sufficient data for each case study were not available to the authors. However, the financial mechanisms are clearly defined. The revenue stream from subscription to the community/platform (BM 1.2.4) is the most crucial aspect across the existing business models for financing mechanisms. Except for the four research and pilot projects, which belong to non-profit organizations and are mainly financed by the German government or other private institutions and companies (BM 1.2.5), the other eleven cases rely on single or multiple finance resources, in which seven cases (64%) generate revenue mainly from fixed subscription fees through the creation of communities. Only one company (Enyway) uses the community investment bonds to develop regional RES, and none of the cases donate electricity in order to reduce fuel poverty.

Table 7. Summary of the most promising business models for P2P ETP.

Beliefs	BMs	Serving household needs	Action taken	Value proposition(s)	Revenue streams	No. of cases
	BM 1.1	Lack of initial investment	Leasing model	Economic	Leasing and maintenance	1
	BM 1.2.1	Purchasing electricity	Smart contracts	Economic, social	Energy-eBay	9
	BM 1.2.2	Saving cost of energy	Free electricity	Economic, social	Energy service contracts	2
Attitude	BM 1.2.3	Energy self-sufficiency	(Virtual) battery	Social, environmental	Subscription fee	4
	BM 1.2.4	Sharing electricity	Community creation	Social, environmental	Subscription fee	9
	BM 1.2.5	Low-cost electricity	Subsidized platform	Economic, social	No revenue stream	4
	BM 1.2.6	Fuel poverty	Donating energy	Economic, social	No revenue stream	-
	BM 2.1	Employed technology	blockchain tech.	Technological	Energy service contracts	8
PBC	BM 2.2	General perceived influence	RES integration	Economic, environmental	RES to local consumers	12
	BM 2.3	Specific perceived influence	Invest in bonds	Economic, social	Energy service contracts	1
Norms	BM 3	Friends referral	Community creation	Economic, social	Signing extra contracts	5

Table 8. Taxonomy of P2P energy trading platforms and existing research projects in Germany with respect to their business models.

Case studies	BM 1.1	BM 1.2.1	BM 1.2.2	BM 1.2.3	BM 1.2.4	BM 1.2.5	BM 2.1	BM 2.2	BM 2.3	BM 3	Sum
LUtricity		X				X	X	X			4
SonnenFlat	X		X	X	X		X	X		X	7
Lition		X			X		X	X		X	5
Pebbles		X				X	X	X			4
SENEC.Cloud				X	X						2
Tal.Markt		X			X		X	X		X	5
E.ON SolarCloud				X							1
Buzzn		X			X			X			3
sonniQ+				X							1
LAMP		X	X			X	X	X			5
Shine Community					X			X			2
Regional-energie					X			X		X	3
Enyway		X			X		X	X	X	X	6
Stromodul		X			X			X			3
RegHEE		X				X	X	X			4

3.6 Conclusions

According to our survey results based on a broad sample of German homeowners, to the applied business models, and to the limitations, we can carefully draw some lessons learned. Thus the current paper is not only primarily interesting for researchers in Germany, but the details and findings from the topic covered, also make it appealing to readers around the world.

Our findings show that cost-savings and financial benefits play an essential role in HHs' decisions to purchase solar PV systems and to become prosumers. In this case, these groups of prosumers may not care about ecological reasons, energy-sharing within a community of prosumers, or having a good feeling about the consumption of self-generated electricity, but simply want to increase their financial benefits by participating in a P2P energy-sharing community or platform, and thus save on their energy costs. This is also in line with the study of Kaschub et al. (2016) which was conducted in Germany. However, other studies show that HHs which intend to participate in P2P electricity trading appreciate the opportunity of sharing energy generation and consumption more than saving on energy costs (Oberst and Madlener, 2015; Hackbarth and Löbbe, 2020; Mengelkamp et al., 2018b). Thus, we have suggested a package of business models for future energy service providers in order to increase HHs' financial benefits and to enable them to share their surplus electricity and at the same time to increase HHs' energy self-sufficiency.

Although by 2020, there were more than 2000 electricity suppliers and utilities operating in the German energy market, we could identify very few case studies (fifteen) that offer P2P energy trading within a platform or some energy-community-building for HHs. Nevertheless, according to our key findings, we predict that more energy companies and utilities will apply our proposed P2P energy trading business models to their core business in the coming years. This argument is also in line with previous research (Karami and Madlener, 2021), based on which future electricity retailers are expected to take a more consumer- and prosumer-centric approach and provide their private customers with energy-sharing platforms.

We find that future energy retailers' business models for P2P ETPs and communities are more prone to follow two primary business models. Firstly, companies' policymakers need to focus more on creating P2P energy-sharing communities or platforms where prosumers and consumers can trade electricity together rather than a rigid online tool that only enables them to store electricity. Secondly, they may integrate regional RES and concentrate on supplying local energy consumers. This is apparent because more than half of the case studies only offer services to regional prosumers and consumers and exclude households living outside of their district. Moreover, regional RES integration will offer economic VPs by suggesting the chance for low-cost or premium local energy prices (Mengelkamp et al., 2019b) and environmental VPs through decreasing local emissions during generation by shifting towards renewables (Rae and Bradley, 2012).

Although all the cases seem similar in practice (all offer energy trading and sharing possibilities through a digital platform and/or community), they can vary fundamentally according to their presenting value, fulfilling HHs' needs, and operating business models. This is evident considering that two case studies apply only one business model from our proposed business model package, whereas the rest employ at least two business models in their leading business model portfolio and consequently deliver more VPs to the households. Valuable business models in P2P markets establish a multi-directional value chain and enable different stakeholders to participate (Meena et al., 2019). The multi-directional value chain can oppose utilities' traditional business models by creating innovative ways in order to secure profitability for their respective P2P stakeholders (Scheller et al., 2018).

Besides the business model development process and operational improvement of the P2P ETPs, legal frameworks must be reviewed. Regulatory policymakers need to pave the way for new market participants – such as start-ups, research institutions, investors, and other stakeholders – by removing the existing legal obstacles and attracting their attention to grow the number of dedicated businesses developing or operating energy communities and platforms.

Although our study expands previous research in the P2P ETPs business model field, it is necessary to mention some limitations. First, our results are reflected from a survey sample consisting of 1618 HHs in Germany (excluding commercial and industrial buildings), including 307 prosumers and 1311 energy consumers, which may deliver potentially biased results. This can be observed in Table 1, where the ratio of participants is considerably different from the German population statistics in terms of participants' gender, age, education, and – more importantly – their disposable income. Second, as business models are dependent on different circumstances and settings such as regulatory limitations, we have not tested our proposed business models yet on any P2P ETP to check whether they might be successful in practice or not. This can be done in principle and that consumer acceptance of business models, and thus diffusion/upscaling, has an impact on the commercial success, also because of economies of scale and sunk costs to be recouped, e.g. for smart grid technology investment. Since most business case studies are young and have not yet published any financial report of their operation, we also could not find sufficient data to assess their business models.

Additionally, since P2P electricity trading platforms are currently relatively unknown opportunities for HHs, we did not ask them directly about these and how they operate in our survey, but instead just pointed to the opportunities they can offer to prosumers based on our in-depth literature review. Consequently, we recommend future research to apply, adapt, and promote the suggested business models and measure their success quantitatively. Moreover, it needs to focus on the implementation of sustainable business models on the P2P ETPs, specifically since studies that have been undertaken in this field so far are still scarce, future research can address business model issues by gathering survey data from members and interviewing stakeholders of real-world P2P ETP projects. In our study, we did not use the households' electricity usage patterns. The potential of P2P energy trading is strongly dependent on the load and the generation profiles. Considering households having solar PV systems which are only able to operate during the daytime (generation side), these are then matched with the load profile. Therefore, the usage patterns are important for the volume of P2P trading possible. This is a case study of Germany, and there are others from South Korea (Lee and Cho, 2020; Chung, 2020), the UK (Braunholtz-Speight et al., 2020; Mujeeb et al., 2019; Lüth et al., 2018), Portugal (Pires Klein et al., 2020), and Australia (Tushar et al., 2020a). The literature is still scarce regarding such country studies investigating preferences and motivations for P2P electricity trading, despite its global, path-breaking potential. Thus, we need more such country case studies to broaden the empirical analysis in this field.

Appendix 1: Research and pilot projects

The Landau Microgrid Project (LAMP)[7] is a German research project run by the Karlsruhe Institute of Technology (KIT) and Energie Südwest AG's energy utility since 2017. It aims at analyzing local energy market behavior, promoting the use and expansion of local renewable generation, establishing an energy community, and establishing local energy balances to reduce grid expansion. LAMP has been live since October 2018 and has 20 residential consumers and two producers trading local electricity on a 15 min merit-order market.

Pebbles[8] is a German demonstrator and research project run by Allgäu Netz, Allgäu Überlandwerk, Siemens, Hochschule Kempten, and Fraunhofer FIT since 2018. Its goals are developing and demonstrating concepts for P2P energy sharing, grid services, and new business models, and especially the allocation of decentralized flexibility for increasing the share of local self-consumption. Trading began in 2020. It comprises 15 local and numerous virtual participants trading electricity on a 15 min basis in a day-ahead market.

In the LUtricity[9] research project, Technische Werke Ludwigshafen AG (TWL) investigates how an autarkic, sustainable power supply can be achieved by using decentralized energy. The plan is to simulate an independent electricity community made up of private and commercial consumers and producers. The LUtricity research project participants are connected to an extensive TWL electricity storage system to form a virtual network. In addition to the existing electricity meter, all participants

[7] https://energie-suedwest.de/unternehmen/projekte-dienstleistungen/lamp/

[8] https://www.pebbles-projekt.de/en/

[9] https://www.twl-kurier.de/twl-foerdert-die-nachhaltige-stromversorgung-2801

receive a device that continuously and securely transmits energy consumption and electricity generated to the blockchain. Based on this data, a balance between electricity supply and demand is to be simulated.

The RegHee[10] research project aims to explore, develop, and test a blockchain-based P2P market for distributed generation and storage units, including labeling in Germany. To this end, existing blockchain systems will be analyzed to inform the system architecture design. Afterwards, on- and off-chain solutions, such as smart contracts, will be developed to enable direct automated trade between local prosumers and end-users. It is an explicit objective that, where possible, the developed platform will operate under current regulatory and energy economics frameworks. A reference system employing a centralized architecture and exhibiting comparable functionality will be implemented and compared.

[10] https://www.ei.tum.de/en/ewk/forschung/projekte/reghee/

Chapter 4

Sustainability Performance of Rural Municipalities in Germany

4.1 Introduction

Sustainable development has been a subject of ongoing debate since its inception and continues to generate discussions today. Communities and sub-national regions worldwide have endeavored to customize sustainable development according to their local contexts, taking inspiration from a variety of frameworks. Notably, over the last years the 17 sustainable development goals (SDGs) and 169 indicators, adopted by 193 countries in 2015 under the United Nations (2015), have served as a reference point. Nevertheless, there is still considerable controversy surrounding the interpretation of sustainable development in local contexts and the appropriate approaches for its implementation (Hopwood et al., 2005).

Sustainable rural development encompasses efforts to enhance the well-being of rural communities while safeguarding natural resources for future generations. Its objective is to achieve a harmonious and enduring development along the lines of the goals of the rural communities by tackling social, economic, and environmental issues. Analyzing sustainable rural development is crucial as it provides a holistic framework for addressing various challenges prevalent in rural areas, including poverty, unemployment, and environmental degradation. Such analysis also helps in identifying key stakeholders and their respective roles in promoting sustainable rural development, as well as determining best practices for attaining this objective. To formulate policy proposals and action plans that foster sustainable rural development, it is essential to recognize the specific factors and obstacles present in rural communities. These may include inadequate infrastructure, limited access to resources, and weak governance structures (United Nations, 2022; World Bank, 2022; Marsden et al., 2001; Masot et al., 2015).

Moreover, rural areas hold significant importance for the European Union, as they are a priority within the funding measures offered to the EU Member States. The EU Rural Development Policy 2014 – 2020, also referred to as the second pillar of the Common Agricultural Policy, plays a crucial role in assisting rural areas within the European Union to address the diverse range of environmental, economic, and social challenges and opportunities that emerge in the 21st century. This policy framework aims to support and empower rural communities in navigating the dynamic landscape of the modern era (European Commission, 2013).

Among the European countries, Germany's prominent role in sustainability is widely acknowledged, regarding its high environmental standards, strong dedication to renewable energy and sustainable practices, and its urbanization (Yang, 2022). According to The German Federal Government (2021b,a) Germany has implemented a range of policies, initiatives, and programs to foster sustainable development, extending its efforts also to encompass rural areas. Germany boosts diverse rural landscapes, encompassing agricultural regions, nature reserves, and villages. Studying the sustainability performance of rural municipalities within a country renowned for its sustainability endeavors offers invaluable insights that can be relevant to other regions confronting similar challenges.

Germany's comprehensive data collection and reporting systems are noteworthy, providing a wealth of information for assessing sustainability performance. Germany's robust data infrastructure surpasses that of many other nations, making it an apt choice for conducting this study. The transferability of findings is another advantage of examining sustainability performance in German rural municipalities. Germany's experiences and practices in sustainable development can serve as a valuable reference for other countries and regions aspiring to enhance sustainability in their own rural areas.

Yang (2022) investigated the role of urban expansion within the 'Energiewende' in addressing challenges to the sustainable energy transition in Germany. His study aimed to explore the academic and historical foundations of the energy transition, analyze relevant events showcasing urban expansion, and identify potential solutions. Drexler et al. (2022) employed the Multi-Level Perspective and an interdisciplinary framing approach to examine how incumbent actors in the automotive industry in Germany framed the topic of "transition of mobility and transport" in their public communication during the year 2020. The study aimed to provide insights into the framing strategies used by these actors and their implications for socio-technical transitions in the mobility sector.

Meister et al. (2020) focused on examining the support provided by municipalities to energy cooperatives at the local level, as well as the relationship between this support and national context conditions. The analysis reveals that municipal support can be advantageous for energy cooperatives by addressing key limitations they face in Germany. Klemm and Wiese (2022) proposed the utilization of multi-criteria optimization methodologies that incorporate key indicators such as absolute greenhouse gas emissions, absolute energy costs, and absolute energy demand. They emphasized the importance of employing specific indicators that are relevant to the final energy demand or the number of inhabitants for effective benchmarking and comparative analysis. Their example scenarios demonstrated modeling strategies to optimize the sustainability of urban energy systems in Germany.

The limited literature on benchmarking for rural development highlights the need for further research in this area. Our study presented here seeks to fill the research gap to some extent and enhance the understanding of the sustainability performance of rural municipalities in Germany, to set benchmarks for improving their performance, and to guide policymakers in their sustainable development policy actions. Accordingly, the five methodological stages of our study can be defined as follows:

(1) To systematically select sustainability performance indicators for comparing rural municipalities for benchmarking.

(2) To decide on the preferred method and process of sustainability benchmarking in terms of quantifiable economic, social, ecological, and technological aspects.

(3) To efficiently and effectively measure, compare, and evaluate the sustainability performance of rural municipalities.

(4) To visualize the outcome graphically in an appealing and transparent form.

(5) To validate the results obtained in terms of plausibility and consistency for a limited set of indicators.

Given the outlined research stages, the primary objective of this study is to identify the most effective approach for illustrating and evaluating the sustainable performance of rural municipalities. Our exploratory study is dedicated to two main research questions: (RQ1) Which KPIs can be used to evaluate rural municipalities' performance (and changes thereof over time) to enable these municipalities to compare their performance with others? (RQ2) How can Germany's rural municipalities improve their sustainability performance in the fields of energy, environment, economy, and digital infrastructure? The outcome of the study will be a set of both KPIs and an assessment framework that is applicable to the German milieu.

The original contribution of the present study to the existing literature is threefold. First, our study contributes to the sustainability literature by systematically reviewing and filtering the most general sustainability policies, indicators, and rating systems relevant to the rural municipalities through a sequential top-down approach. This is original since most of the existing studies emphasize on medium or large cities. Second, our methodological novelty employs "multiple methods" by evaluating and rating the performance of rural municipalities in terms of economic, social, ecological, and most importantly technological aspects through employing and implementing a menu of selected indicators for the first time in Germany.

Third, we have employed radar charts as a visualization tool to effectively communicate the performance of the selected rural municipalities. This allows for a concise and informative representation of multiple variables in a single chart and facilitates the identification of gaps between actual and target values, highlighted areas requiring improvement, and offered a comparative analysis among different municipalities or benchmark references. We believe that the results will also be of interest for municipalities planning new municipal projects, especially as they seek to learn from each other and need to justify investments more and more also in terms of sustainable development goals.

The remainder of this paper is organized as follows. Section 2 presents the literature review and the theoretical frameworks related to the research question. The proposed methodology is outlined in Section 3. The results of the analysis are presented in Section 4. The discussion follows in Section 5. Finally, a conclusion and some policy implications and recommendations are offered in Section 6.

4.2 Literature review

Measuring sustainability performance is a very critical step in sustainable development planning and progress. Indeed, sustainability performance indicators have attracted considerable attention around the world because they are expected to provide a reliable, long-term, easy-to-understand proxy for broader areas of concern for a sustainable development (Wheeler, 2000). While key performance indicators (KPIs) for sustainability are often developed to quantify (and often benchmark) the sustainability of municipalities, it is essential to compare them from the perspective of overall sustainability performance. However, sustainability indicators are typically considered from different domains, for example, energy, water resources, air pollution and transportation, and civil infrastructure, and the indicator categories are typically presented using different units of measurement (Olewiler, 2006).

Sustainability KPIs have been widely addressed in the literature (Mapar et al., 2017; Angelakoglou et al., 2019; Hezri and Dovers, 2006). These indicators are also in line with the need for transitioning the municipalities to more resilient and sustainable alternatives that will work towards reaching, or maintaining, a sustainable development of local communities (Pires et al., 2014; Devuyst et al., 2001; Collier et al., 2013; Mori and Christodoulou, 2012). Therefore, determining an overall sustainability performance assessment becomes a challenging task that requires appropriate scientific approaches that can quantify the sustainability also of diverse municipalities. Sustainability benchmarking is a crucial step to realize the sustainable development goals of different municipalities simultaneously. However, problems and debates naturally arise about the types of indicators to be included in sustainability benchmarking projects and the extent to which some sort of standardization is needed (Ramos and Pires, 2013; Pires et al., 2014). For the German federal government, promoting sustainable development is a fundamental goal and benchmark for government actions taken across the entire nation (and even beyond). Germany's federal government is committed to an ambitious implementation of the 2030

Agenda through a Sustainable Development Strategy which aims to implement the 17 Sustainable Development Goals (SDGs) adopted from the 17 SDGs of the United Nations at three levels – i.e. the federal, state, and municipal level (The German Federal Government, 2021b,a).

Initially, big companies have taken the benchmarking process into account by comparing their performance with the best existing practices (Vorhies and Morgan, 2005; Stewart, 1995). Since the 1990s, a number of articles has been published on the benchmarking process concept. Camp (1989), for instance, defined benchmarking as a tool that enables to identify industry's best practices and that will lead to superior performances. According to Spendolini et al. (1999), benchmarking has two main characteristics: it can be used to learn from any organization, whether or not it is a competitor, and it should integrate the efforts taken to measure processes. Several scholars reviewed the incremental development process towards enhanced performance of some sort in different fields such as manufacturing industries, urban area planning, management firms, and construction projects to enhance performance practices and techniques (Czuchry et al., 1995; Dorsch and Yasin, 1998; Jackson et al., 1994; Yasin, 2002; Dattakumar and Jagadeesh, 2003).

Benchmarking is also widely used to improve the performance and competitiveness of municipalities (Rondo-Brovetto and Saliterer, 2007; Ammons, 2014; O'Loughlin and Wilson, 2021). Luque-Martínez and Muñoz-Leiva (2005) studied the benchmarking concept effectively for municipality planning, and provided a systematic and continuously applicable method that identifies, learns, and implements the most effective practices and capacities from other municipalities in order to improve one's municipality's performance. Local authorities are more likely to be the first candidates for a new generation of governance benchmarking in local levels since they have always been much closer to citizens than regional, national, or international levels of government (Bovaird and Löffler, 2002). In this regard, Ammons (2014) concentrated on providing a framework for evaluating and enhancing the performance of local communities. He argued that by establishing benchmarks and tracking progress towards them, local governments can better identify areas of strength and weakness, and take actions to improve their performance. Ammons emphasized on the importance of using unbiased data and metrics to evaluate municipal performance. He suggests that by measuring performance in a standardized and transparent way, local communities can better understand their strengths and weaknesses, needs and preferences, and make informed decisions about distributing their resources (Ammons, 2014).

López-Penabad et al. (2022) introduced a benchmarking system for assessing rural sustainable development in Galician municipalities in Spain. They identified crucial factors linked to the rural sustainable development index and utilized the Benefit of the Doubt, common weights, super-efficiency, and logistic-geometric methodologies to construct a composite index. This comprehensive index encompassed four dimensions: economic, demographic, social, and environmental. Benedek et al. (2021) conducted a study in Romania with the objective of assessing progress towards achieving the Sustainable Development Goals (SDGs) at the local and regional levels. They introduced the SDG Index as a measurement tool for this purpose. To calculate the SDG Index at the local level, the authors proposed an integrated territorial approach that involved the use of 90 indicators. These indicators were stored and processed in a PostgreSQL object-relational database, allowing for a comprehensive and indicator-based assessment of the SDGs.

Frare et al. (2020) proposed a comprehensive system of sustainability indicators specifically designed to support rural municipalities in Brazil. The study employed a rigorous four-stage methodology to select the indicators. Firstly, the Delphi technique was utilized. Subsequently, 64 indicators were evaluated by 19 mayors from cities in southern Brazil. Their resulting subset of sustainability indicators covered nature and social well-being, sustainable public management, historical and cultural management, sustainability education, new savings for sustainability, and urban planning and accessibility. In the third stage, a fuzzy expert system was employed to establish a decision tree and create a general index for a pilot municipality. This practical application demonstrated the culmination of the study, highlighting the importance of the sample in the final (fourth) step.

Rodrigues and Franco (2020) conducted a study with the objective of organizing indicators and indices that enable the assessment of sustainable development in 308 cities and towns, considering economic, social, and environmental aspects. Their findings enabled the development of a Composite Index for Sustainability, which was established through the application of multivariate statistical techniques such as Exploratory Factor Analysis and Principal Component Analysis. This approach confirmed the scientific rigor and robustness of the index, representing the primary contribution of their research. Furthermore, the results revealed that the dimension of urban sustainability in Portuguese municipalities manifests itself in a three-fold manner.

Hatakeyama (2018) developed conceptual frameworks for sustainable development indicators (SDIs) using Japanese municipal governments as case studies. His findings revealed five SDIs and identified four approaches, emphasizing the most practical and optimal frameworks. The first approach, favored by a majority of local governments, displayed a strong inclination towards socioeconomic policies while neglecting environmental aspects, despite the overarching goal of holistic sustainability. This trend reflects the current sustainability landscape at the local level in Japan. In contrast, the alternative approach aimed to achieve a balanced integration of three dimensions of sustainable development, with a primary focus on well-being. This framework addressed the lack of environmental orientation, potentially contributing to the coherence of public policy implementation.

4.3 Methodology

The literature search for our study was conducted using Google Scholar, and the following keywords were utilized: sustainability, sustainable development, rural, benchmarking, indicator, measure, and dimension. These keywords were selected to specifically target relevant literature on sustainability performance in rural municipalities.

The search criteria included articles published in peer-reviewed journals, conference proceedings, international organizations, and reputable reports related to the sustainability performance of rural municipalities in Germany. The focus was on obtaining recent and relevant publications to ensure the inclusion of up-to-date information and insights. The initial search yielded a significant number of results, which were further refined based on relevance and alignment with the study's objectives. The refinement process involved screening the titles, abstracts, and keywords of the retrieved articles to identify those that specifically addressed the sustainable performance of rural municipalities. The selected articles were then thoroughly reviewed, and their references were examined to identify additional relevant sources that may have been missed during the initial search. This step helped to analyze and characterize rural municipalities and ensure a comprehensive coverage of the literature and minimized the possibility of overlooking key studies or concepts.

Regarding the KPIs sought, the specific types and criteria used in the search were not explicitly mentioned in the provided information. However, the intention was to identify a set of indicators that could effectively measure the sustainability performance of rural municipalities. These indicators may include dimensions such as the economic, social, ecological, and technological ones, as mentioned in the abstract. The search aimed to find studies that utilized and discussed such indicators in the context of rural sustainability benchmarking.

4.3.1 Indicator selection for the benchmarking system

In our study, we first conducted an extensive literature review based on a sequential top-down approach to find the appropriate metrics for our research. In order to identify standard KPIs that are widely acknowledged and corroborated by scientific publications and international organizations, we reviewed the 17 global sustainable development goals (SDGs) set by the United Nations (2015), World Health Organization (2016), The World Bank (2021b) and, additionally, The German Federal Government (2021b,a). After that step, we compiled more than two hundred different measures and indicators. These indicators, in general, all allow to measure and communicate sustainable development progress in an effective and meaningful way. However, many of them were found to be either irrelevant or unreasonable to be directly used for the evaluation of rural municipalities' development in our study.

The UN SDG indicator framework primarily focuses on the challenges faced by developing countries. However, with its extensive list of indicators that are often only vaguely defined, it can become overwhelming and difficult to manage. On the other hand, the United Nations Economic and Social Council (2015) recognizes smart sustainable cities as a significant catalyst for growth, productivity, and employment. According to UN ECOSOC a smart sustainable city is an innovative urban area that utilizes information and communication technologies and other tools to enhance the quality of life, operational efficiency, service delivery, and competitiveness. It also ensures the fulfillment of economic, social, environmental, and cultural needs for both present and future generations. The UN Smart Sustainable Cities Indicators framework offers a well-balanced approach to sustainability across various dimensions. It is characterized by clear definitions and a forward-looking strategic vision. Thus, the set of indicators was filtered in terms of economic, social, ecological, and technological aspects according to the UN Smart Sustainable Cities Indicators framework. At this stage, a subset of 83 indicators was chosen (see Figure 1 and Table 5 in Appendix 2).

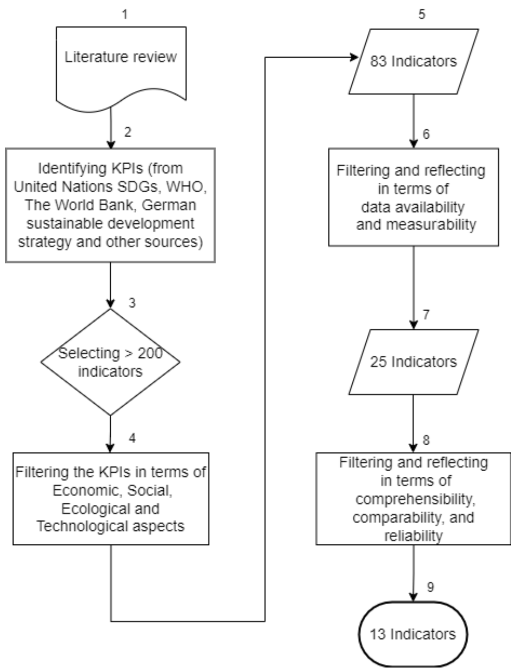

Figure 1. Procedure adopted in the indicator selection for the rural municipality benchmarking system.

In the next step, we selected KPIs that can be used to evaluate rural municipalities' performance and enable these municipalities a comparison with each other. These KPIs can also be operationalized to balance the economic (ECO), social (SOC), ecological (ENV), and technological (TEC) dimensions covered.

Economic Aspects: Economic aspects encompass indicators related to the financial and economic performance of rural municipalities. This may include metrics such as GDP per capita, employment rates, income distribution, poverty levels, investment in local businesses, and economic diversification.

The selected indicators should be available, measurable, easy to understand, comparable across municipalities, and reliable in terms of data sources and accuracy.

Social Aspects: Social aspects refer to indicators that capture the well-being, quality of life, and social dynamics within rural communities. These may include metrics such as access to healthcare and education, crime rates, community engagement, social cohesion, cultural preservation, and social equity.

Ecological Aspects: Ecological aspects refer to the environmental considerations and impacts of human activities. When evaluating indicators in relation to the ecological aspect, the focus is on assessing the sustainability performance in terms of environmental conservation, resource management, and minimizing negative ecological effects. Indicators related to the ecological aspect may include measurements of GHG emissions, energy consumption, waste generation, water usage, biodiversity conservation, and land and habitat preservation.

Technological Aspects: Technological aspects focus on indicators that assess the level of digitalization, technological adoption, and innovation within rural municipalities. These may include metrics such as broadband connectivity, digital infrastructure, e-governance services, technology access and utilization, and innovation capacity.

The selected indicators should satisfy the criteria of data availability (sufficient availability specifically for rural municipalities), measurability (quantifiable and objective measurements), comprehensibility (clear and understandable to stakeholders), comparability (allowing for meaningful comparisons across municipalities), and reliability (reliable data sources and methods).

Therefore, additional filtering regarding data availability and data measurability were applied to the selected 83 indicators. For instance, data for specific indicators are often not available for comparing and setting up targets for performance improvement. Also, sustainable development benchmarking at a local level should account for the fact that simple quantitative and measurable indicators do not always entirely reflect the system's complexity into which a local entity is embedded. In many cases, meaningful benchmarks cannot be derived at all with such indicators. Therefore, in the present study, performance indicators are selected subject to the constraint of availability of reliable data sources to better understand benchmarking. This stage narrowed down the number of KPIs and eventually resulted in 25 acceptable indicators. In a final step, selection criteria such as comparability, reliability and comprehensibility of the indicators were applied as well. This reduced the number of indicators further to 13.

4.3.2 Case study selection

In order to achieve a reliable benchmarking system, a comparison of rural municipalities can be carried out by grouping either municipalities with similar characteristics, e.g. in terms of area and population, or municipalities with varying characteristics, thus allowing for the benchmarking also of very heterogeneous municipalities. The first approach of comparing cities with similar characteristics is adopted in the current study. Therefore, we applied the 13 indicators presented in Table 3 to ten rural municipalities in Germany which were selected based on the following three main criteria: (1) the case studies can be considered as rural areas since their population is below twenty thousand inhabitants (according to BBSR (2011)). (2) Their area is less than 150 km^2 and, most importantly, (3) they have regularly published the most favorable data for our investigation in contrast to other German rural municipalities. After reviewing the profile and the database of more than hundred different rural municipalities in Germany overall, the ten selected rural municipalities with the mentioned criteria for our study are Finnentrop, Weeze, Rehfelde, Eppelborn, Remagen, Wiesmoor, Aulendorf, Limbach, and Roetgen (Table 1), located in seven federal states and ranging from 4,506 – 17,156 in population and 33.16 – 129.71 km^2 in area size.

Table 1. 10 Selected rural communities in Germany.

Municipality	Source	Population (2020)	Federal state	Area (km^2)
Finnentrop	`www.finnentrop.de/`	16,854	North Rhine-Westphalia	104.42
Roetgen	`www.roetgen.de/`	8,650	North Rhine-Westphalia	39.03
Weeze	`www.weeze.de/`	11,228	North Rhine-Westphalia	79.49
Aulendorf	`www.aulendorf.de/`	10,177	Baden-Wuerttemberg	52.36
Limbach	`www.limbach.de/`	4,506	Baden-Wuerttemberg	43.61
Ebersberg	`www.lra-ebe.de/`	12,213	Bavaria	40.83
Alsfeld	`www.alsfeld.de/`	15,941	Hesse	129.71
Rehfelde	`www.gemeinde-rehfelde.de/`	5,221	Brandenburg	46.51
Eppelborn	`www.eppelborn.de/`	16,569	Saarland	47.04
Remagen	`www.remagen.de/`	17,156	Rhineland-Palatinate	33.16

4.3.3 Data collection and analysis

For the empirical analysis (benchmarking), we collected data from statistical offices of the federal and state governments and local publications. We also relied on analysis of publicly available documents, including municipality websites and publications, media articles and press releases, and the review of academic and grey literature. However, it should be noted that the availability of relevant, quantitative, precise, comparable, and authentic data collected from real-life phenomena is essential in selecting indicators and performing benchmarking successfully. For our benchmarking system, the availability of statistical data was a bottleneck, particularly at the rural municipalities level. Data of specific indicators are often not available for comparing and setting up targets for performance improvement. Because the data collection process had its limitations, we moved from a longer, desirable list to a somewhat shorten but operable one. Thus, we benchmark the rural municipalities considered using the most recently released data from databases including Table 2.

Table 2. Data used for the rural municipality benchmarking

No.	Database	Description and references used
1.	WiFi map	Map of available public hot-spots Molkenthin (2021)
2.	Noise map	Map of noise exposure STMUV (2021); MUNV (2021)
		LUBW (2021b); HLNUG (2021); MLUK (2021)
3.	Air quality	Air quality measuring stations Umweltbundesamt (2021); EKL (2021)
4.	Broadband atlas	High speed Internet coverage BMDV (2021)
5.	General statistics	List of rural municipal publications IT.NRW (2021)
		BLS (2021); HLGL (2021); BWSL (2021); SBB (2021)
6.	Energy atlas	Map of renewable energy resources Energy Map (2016); Bayern (2021)
		LANUV (2021); LUBW (2021a); Regionalverband FRM (2021)

According to Table 2, (1) the WiFi map database provides around 30,000 locations marked on the map for WLAN hot spots in Germany, based on the latest available data. This results in a detailed overview of the Germany-wide spread of public access. (2) The map of noise exposure for five different selected states – such as North Rhine-Westphalia (NRW), Bavaria, Hesse, Baden-Wuerttemberg, and Brandenburg – illustrates the close connection between residential location, environmental and health pollution every couple of years. (3) The air quality database presents the recently measured and calculated concentrations of three pollutants (PM_{10}, NO_2, and ozone), with the health-criticality of the three measured concentrations, and determines the overall result across the country. (4) The broadband atlas as the central information medium for broadband coverage presents the initial results of data collection for broadband availability in Germany as of June 2021. The results are based on voluntary data submissions by broadband Internet providers. (5) General statistics include data from all German federal states such as statistical reports, municipal profiles, and joint publications. (6) Maps related to the installed capacity of variable renewable energy sources can be found in energy atlas databases.

After completion of our data collection process according to Figure 2, we used the published data from the above-mentioned databases, including municipality websites and publications. It should be noted that we aimed at using the latest published data for our selected indicators and, also, to provide a dynamic benchmarking system over time that measures the progress over time. However, the latter was not possible, generally, due to the unavailability of historical data that makes the performance measurement of rural municipalities much more difficult. This allowed us to provide a snapshot of their sustainability performance at a specific point in time. Therefore, in the end, we are only able to provide a static benchmarking system that illustrates the sustainable development of the selected rural municipalities based on the latest achievement they could record in their recent publications. Finally, we implement a simple and easy to understand aggregation method to derive a single value for each municipality, addressing the concern regarding the merging of different units of measurement.

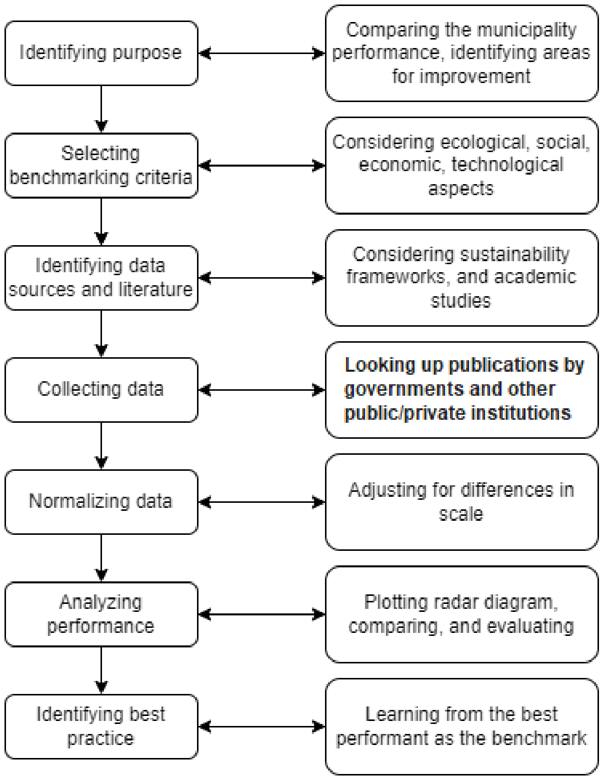

Figure 2. Benchmarking process for the selected rural municipalities.

4.4 Results

Based on the systematic implementation of methodological stages, the rigorous literature review process, meticulous indicator selection, and stringent filtering criteria, the study's findings are summarized in Table 3 and are explained in some detail in the following.

Table 3. Indicators used to assess the sustainability performance of municipalities in Germany.

SDG	Code	Indicator	Source	Unit
Environmental	ENV1.	Emission of greenhouse gases	Destatis (2021)	Tons per capita
Environmental	ENV2.	Territorial protection	BMUV (2018)	Percentage
Environmental	ENV3.	Total phosphorus in flowing waters	Federal Environment Agency Destatis (2021)	mg per liter
Energy	ENV4.	Promotion of renewable energy sources	BMWK (2020)	Percentage
Energy	ENV5.	Economic and efficient use of energy sources	Destatis (2021)	Percentage
Life quality	ENV6.	Ambient air quality improvement	WHO (2021)	µg per cubic meter
Life quality	ENV7.	Reduction of noise pollution	WHO (2018)	dB (A)
Economical	ECO1.	New business registrations	The World Bank (2021b,a)	No. registered companies
Economical	ECO2.	Reduction in income inequality	Destatis (2021)	Thousand Euros
Social	SOC1.	Civic engagement	The Federal Government (2017)	No. of hours
Social	SOC2.	Access to public transport	UN Habitat (2021)	Percentage
Technological	TEC1.	Access to public free WiFi	European Commission (2021)	No. access points available
Technological	TEC2.	Access to high-speed Internet	BMDV Destatis (2021)	Percentage

Coding used: ENV Ecological, ECO Economic, SOC Social, and TEC Technological

4.4.1 Ecological (ENV)

Local governments play a critical role in protecting the environment for enabling a sustainable development. An excellent example is the role of municipalities in combating problems arising due to climate change by taking preventive measures and mitigating the causes of climate change, including greenhouse gas emissions (GHG) (Ahvenniemi et al., 2017). As climate change is a global problem that requires a global solution, the contribution of a local municipality is pro rata, and typically derived and downscaled from the GHG mitigation goal/s set by the state or federal government.

ENV1. Emission of greenhouse gases: the German federal government aims to reduce GHG emissions in Germany by at least 55 percent in 2030 compared to 1990 levels (Destatis, 2021). This indicator measures generated emissions of the so-called "Kyoto basket" of GHG, integrated into a single indicator expressed in units of CO_2 equivalents, using the global warming potential of each gas. The GHG intensity of energy consumption is the ratio between energy-related GHG emissions and gross inland energy consumption. It expresses, for instance, how many tons of CO_2 equivalent from energy-related GHGs are emitted per unit of energy consumed in a specific economy but could also include land use change.

ENV2. Territorial protection: this indicator provides information about the extent of strictly protected areas, including nature reserves, national parks, and designated zones within biosphere reserves, as a proportion of the available land area. A higher indicator value indicates a larger proportion of the land area covered by these protected areas. This indicator reflects efforts to preserve and conserve natural habitats and biodiversity, contributing to the overall conservation and sustainability goals in Germany (BMUV, 2018).

ENV3. Total phosphorus input in floating waters: the indicator shows the proportion of those monitoring sites where the guideline values for phosphorus (PO_4) per liter in watercourses for good ecological status are met in specific types of watercourses. This indicator measures the concentration of phosphate in the dissolved phase from water samples from river stations and aggregates to annual average values. At high concentrations, phosphate can cause water quality problems by triggering the growth of macrophytes and algae (Destatis, 2021).

ENV4. Promotion of using renewable energy sources (RES): this indicator reflects the share of electricity in gross electricity consumption from RES. The gross final energy consumption is the energy utilized by end consumers (final energy consumption) plus grid losses and self-consumption of power plants. According to the German government's energy concept, the share of electricity from RES, measured in gross electricity consumption, should increase to at least 65 percent by 2030 and at least 80 percent by 2050 (BMWK, 2020).

ENV5. Economic and efficient use of energy sources: this indicator shows the development of value added per unit of final energy input. The term "final energy" refers to the energy used in the form of thermal or electrical energy in the production sectors to manufacture goods or by private households for satisfying their end-use energy needs. Primary energy consumption, on the one hand, indicates how much energy was consumed in a country in the energy sectors for conversion purposes and, on the other hand, how much energy is needed for production activities, transport, and private households. According to the German federal government's energy concept, final energy productivity is to be increased by 2.1 percent annually between 2008 and 2050. At the same time, primary energy consumption is to be reduced by 50 percent by 2050 (in both cases compared with 2008 levels) (The German Federal Government, 2021b,a).

ENV6. The sustainability indicator "Air quality in municipalities" is relevant and informative for assessing immission[1] pollution in municipalities due to the effect and general occurrence of particulate matter (PM) and NO_2. The calculation is based on data from urban background monitoring stations (according to the EU Council Decision on Information Exchange 97/101/EC). The sub-indicators PM_{10} and NO_2 are defined as arithmetic averages of the respective annual mean values. Therefore, they characterize the mean long-term background levels of the two air pollutants PM_{10} and NO_2 as follows:

ENV6.1. Ambient air quality improvement 1 (PM_{10}): the PM_{10} indicator shows the amount of particulate matter (dust particles with a diameter of smaller than 10 micrograms) per cubic meter

[1] Immission is the opposite of emission, which refers to the release of pollutants or other substances into the environment. Immission is the actual exposure of individuals or the environment to the emissions or external factors.

of air. The guideline value for fine dust recommended by the World Health Organization (WHO) of an average of 20 micrograms per cubic meter of air per year should be achieved throughout Germany by 2030 (WHO, 2021).

ENV6.2. Ambient air quality improvement 2 (NO_2): concerning the reduction of nitrogen dioxide (NO_2) concentrations, the WHO guideline value for NO_2 is 40 micrograms per cubic meter as an annual average. Therefore, the emission of air pollutants should be reduced by 45 percent in 2030 compared to 2005 levels (WHO, 2021).

ENV7. Reduction of noise pollution: in October 2018, WHO published guidelines on environmental noise for the European continent in order to reduce the average noise pollution from road traffic (WHO, 2018). The indicator measures the population's percentage in noisy areas that are permanently exposed to a pre-defined noise level and is implemented by two sub-indicators:

ENV7.1. 24-hour noise immissions, 65 dB: this sub-indicator shows the proportion of people affected by environmental noise subject to mandatory mapping and has a 24-hour noise index that aims to limit any values higher than 65 dB in the total population of the federal state.

ENV7.2. Nighttime noise immissions, 55 dB: this sub-indicator shows the proportion of people affected by environmental noise subject to mandatory mapping and has a nighttime noise index that aims to limit any values higher than 55 dB in the total population of the federal state.

4.4.2 Economic (ECO)

The selected indicators for the development of the economic are:

ECO1. New business registrations: new businesses registered are the number of new limited liability corporations (or equivalent[2]) registered in a calendar year in the municipality concerned. Business registrations for new businesses are used below as an indicator. The units of measurement are private, formal sector companies with limited liability. Note that though business registrations are initially only declarations of intent that do not necessarily lead to the actual establishment of a business, the data nevertheless give an idea of the dynamics, such as start-ups (The World Bank, 2021b,a).

ECO2. Reduction in income inequality: (nominal) disposable income is an indicator of the (monetary) wealth of private households. Disposable income is calculated as the annual income available to private households after income redistribution. For regional comparisons, disposable income is related to the respective number of inhabitants (per capita income) (Destatis, 2021).

[2]These include general partnership (Offene Handelsgesellschaft, OHG), limited partnership (Kommanditgesellschaft, KG), limited liability company (Gesellschaft mit beschränkter Haftung, GmbH), an entrepreneurial company at limited liability (Unternehmergesellschaft (UG)

4.4.3 Social (SOC)

Social sustainability refers to the capacity of a society to meet the present and future needs of its members, promoting their well-being and ensuring social equity and justice. It encompasses aspects such as community engagement, access to basic services, human rights, social cohesion, and cultural diversity.

SOC1. Civic engagement: this indicator measures the number of hours spent by individuals in Germany dedicated to civic and voluntary activities. It serves as a recognized measure of social cohesion and overall well-being within the country. The significance of volunteering and civic engagement has been particularly evident in dealing with the refugees coming to Germany (The Federal Government, 2017).

SOC2. Access to public transport: this indicator measures the proportion of the population that has convenient access to a public transportation stop within a reasonable walking distance. It considers a radius of 500 meters for low-capacity transport modes such as buses, and 1000 meters for high-capacity transport modes such as trains and ferries, along the street network (UN Habitat, 2021).

4.4.4 Technological (TEC)

Two leading indicators were selected for the digitalization category which measure the Internet connectivity of the rural municipalities:

TEC1. Access to public free WiFi: this indicator measures the number of public free WiFi access points installed per year and the number of connections they generate across the rural municipalities. WiFi access points provide empirical proof to overcome the restricted scope of Internet geography examinations on wired infrastructure. The coverage of WiFi access points can be represented as geometrical circles surrounding specific areas in municipalities. The wireless Internet technology expands the connectivity of the fixed Internet infrastructure by delivering untethered and ubiquitous access (European Commission, 2021; Zook, 2006).

TEC2. Access to high-speed Internet: the indicator measures the percentage of households connected to fiber to the home (FTTH) with a minimum speed of 1000 Mbits per second. It ensures good connectivity of the population by providing efficient digital infrastructures and focusing on the fixed (wired) broadband subscriptions (Destatis, 2021).

4.4.5 Normalization, weighting, and aggregation of indicators

In order to use a consistent benchmarking system with an identical unit of measurement, we converted and normalized all the achieved values according to Eq. (1) and (2). The obtained values were normalized to ensure easy comparability on a scale of 0 to 1. We employed two normalization methods: the min-max *(v')* and max-min *(v*)* techniques. In the normalization process, *(v)* represents the value of the raw data, while min*(v)* and max*(v)* determine the lower and upper bounds representing the worst and best performance, respectively. The normalized values, *(v')* and *(v*)*, are obtained through re-scaling. For the majority of indicators, we utilized the min-max*(v')* normalization method with (Eq. 1). In this approach, a score of 0 indicates the worst performance, while a score of 1 represents the highest performance.

In the case of indicators such as ambient air quality improvement, total phosphorus input in flowing waters, and reduction of noise pollution the max-min*(v*)* normalization method is applied with (Eq. 2). This means that 0 indicates the worst performance and 1 the best performance.

In order to aggregate the individual indicator values into a single value for each municipality, we utilized existing frameworks as presented in Table 4. These frameworks provided a structured approach to combining the various indicators and capturing the overall sustainability performance of each municipality.

$$(\text{v'}) = \frac{\text{v} - \min(\text{v})}{\max(\text{v}) - \min(\text{v})} \tag{1}$$

$$(\text{v*}) = \frac{\max(\text{v}) - \text{v}}{\max(\text{v}) - \min(\text{v})} \tag{2}$$

Once the indicators were normalized, we multiplied each indicator value by its respective weight. Table 4 presents 3 different frameworks for weighting the indicators related to sustainable development. However, upon examination, we found that none of the frameworks explicitly include weighting for social and technical indicators that we used. As a result, we decided to utilize the equal weighting method for our assessment. By using the equal weighting method, we aimed to avoid any bias or subjective judgment that could arise from assigning different weights to different indicators. This implies that according to (Eq. 3) the relative weight of each indicator is inversely proportional to the number of (in total 13) indicators.

$$w_i = \sum_{i=1}^{n} \frac{1}{n} \tag{3}$$

Whereas n is the total number of indicators, w_i is the weight assigned to indicator i. We multiplied each normalized value v_i by its corresponding weight w_i. The resulted score s_i represent the weighted score for indicator i, according to (Eq. 4):

$$s_i = w_i \cdot v_i. \tag{4}$$

After obtaining the weighted scores s_i for each indicator, we proceeded to aggregate them. The aggregation was performed by summing up the weighted scores (S), resulting in a single value that reflects the overall sustainable performance of each municipality (see Eq. 5). This aggregated score ranged between 0 and 1, with higher values indicating better sustainability performance.

$$S = \sum_{i=1}^{n} s_i \tag{5}$$

This approach provides a holistic evaluation of municipalities by considering multiple indicators and their respective weights. By aggregating the indicator values, we can effectively capture the complex nature of sustainable development and present it in a simplified manner with a single value for each municipality. This facilitates the comparison and ranking of municipalities based on their sustainability performance.

Table 4. The reference data used to normalize the metrics according to Frare et al. (2020); Hatakeyama (2018); Rodrigues and Franco (2020) and equal weighting.

Indicator	Code	Indicator	Frare et al.	Rodrigues and Franco	Hatakeyama	Equal weight (w_i)
Environmental	ENV1.	Emission of Greenhouse gases	-	0.369	0.69	0.0833
Environmental	ENV3.	Total phosphorus in flowing waters	-	0.369	0.61	0.0833
Energy	ENV4.	Promotion of renewable energy sources	5.94	0.369	0.64	0.0833
Energy	ENV5.	Economical and efficient use of energy sources	4.36	0.369	0.57	0.0833
Life quality	ENV6.	Ambient air quality improvement	-	0.369	0.72	0.0833
Life quality	ENV7.	Reduction of noise pollution	-	0.245	0.60	0.0833
Economic	ECO1.	New business registrations	7.89	0.386	0.64	0.0833
Economic	ECO2.	Reduction in income inequality	7.15	0.386	-	0.0833
Social	SOC1.	Civic engagement	-	0.245	0.59	0.0833
Social	SOC2.	Access to public transport	5.73	0.245	-	0.0833
Technological	TEC1.	Access to public free WiFi	-	-	-	0.0833
Technological	TEC2.	Access to high speed Internet	-	-	-	0.0833

4.4.6 Visualizing the data

To graphically illustrate the performance of the selected rural municipalities, we make use of radar charts. Radar charts are handy for comparing a large number of variables and displaying them in compact form in one single chart. Radar charts help to identify the prevailing gap between actual and target values for selected municipalities. Furthermore, they provide insights into the dimension seriously lacking in acquiring the target values. A radar chart also enables to study the scope of sustainable improvement in every indicator subset considered. Radar charts present the data more clearly and allow to compare several different case studies with each other, or to compare them with the benchmark. Also, one can use different measurement scales in a radar chart.

After equally weighting the indicators based on (Eq. 3), we multiply each indicator's normalized value v_i by its corresponding weight w_i to obtain a weighted score s_i according to (Eq. 4). This multiplication reflects the importance of the indicator in the overall assessment of sustainability. The resulting weighted score provides a measure of the individual indicator's impact on the municipality's sustainability assessment. A higher weighted score s_i indicates a stronger contribution of the indicator to the overall sustainability performance, while a lower score suggests a relatively lower impact.

After testing and applying the indicators for each selected local community and comparing the results, we arrived at two different comparing scenarios as follows:

(1) Comparison of the rural municipalities considered within the same federal state: In this scenario, all rural municipalities within the state of North Rhine-Westphalia are compared with each other, and the results are shown in Figure 3. Thus, they mostly have the same sustainability and other policy goals explicitly defined by the federal state. As can be seen, all municipalities considered have almost the same performance in terms of ecological and economic indicators, including improving ambient air quality, reducing phosphorus input in flowing waters, reducing noise pollution (during the day and at night), and registering new businesses. Regarding the digitalization aspect, all three municipalities are clearly underperforming. However, for the energy and environmental indicators, they have a quite good performance. The municipality of Weeze, with the highest share of generated renewable electricity among all the municipalities included in the sample, has the lowest GHG emissions. On the contrary, the municipality of Roetgen has the lowest share of renewable electricity generation, yet produces a higher volume of CO_2 per capita.

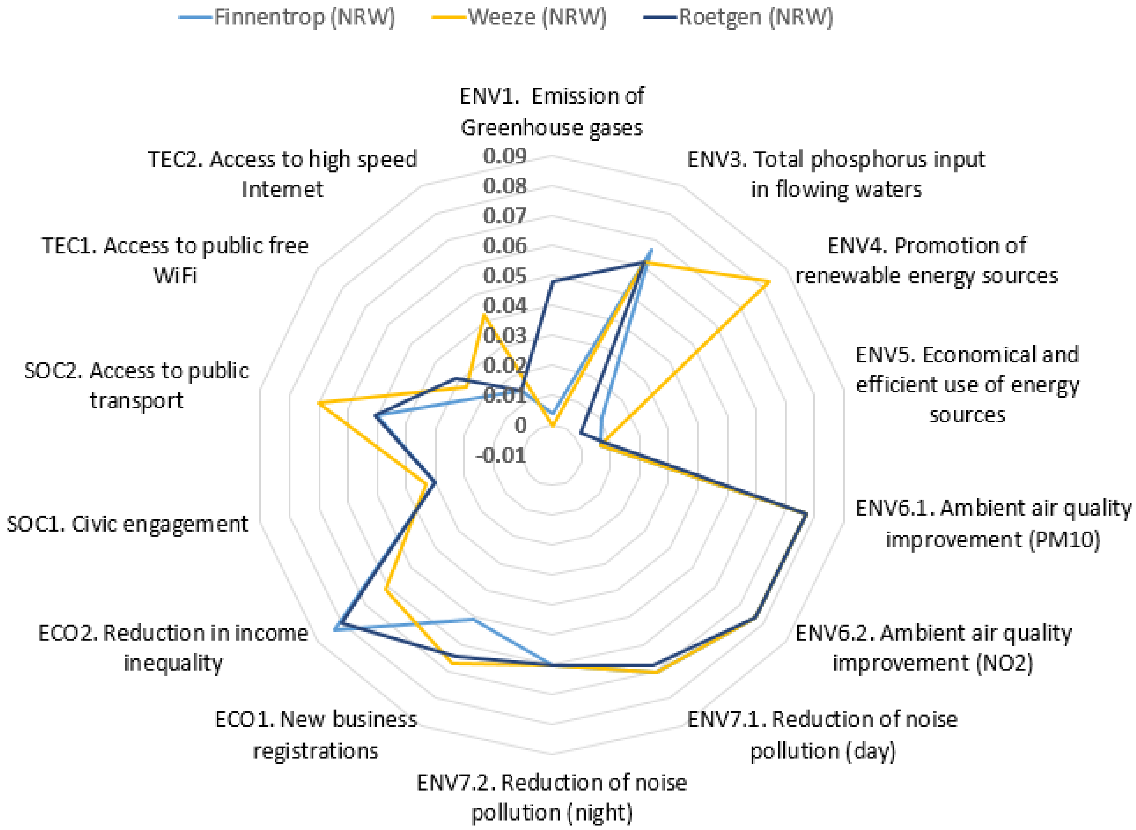

Figure 3. Comparison of performance of the three selected municipalities within the state of North-Rhine Westphalia (NRW) based on the resulted score s_i for the selected indicators.

(2) Comparison of all municipalities across the country combined: This scenario is more comprehensive because it compares the sustainability performance of all rural municipalities considered and provides more information about the actual progress of municipalities across the country (in seven out of the 16 German federal states overall, cf. Table 1). As shown in Figure 4, the diverse sustainability performance of all the analyzed rural municipalities is presented using the benchmarking system. It can be seen that those rural municipalities perform strongly in terms of quality of life indicators (ENV6. and ENV7.). Accordingly, for the air quality indicators ENV6.1. and ENV6.2., which refer to PM_{10} and NO_2, respectively, all the selected municipalities have reached the target value. For indicators such as noise pollution reduction, the hope is that the target values will be reached earlier if the rural municipalities measure the existing noise regularly and reduce the noise pollution accordingly. Based on the achieved data, the overall performance of the two municipalities Ebersberg and Roetgen are more sustainable than the others because their graphs are shown to be closer to the benchmark.

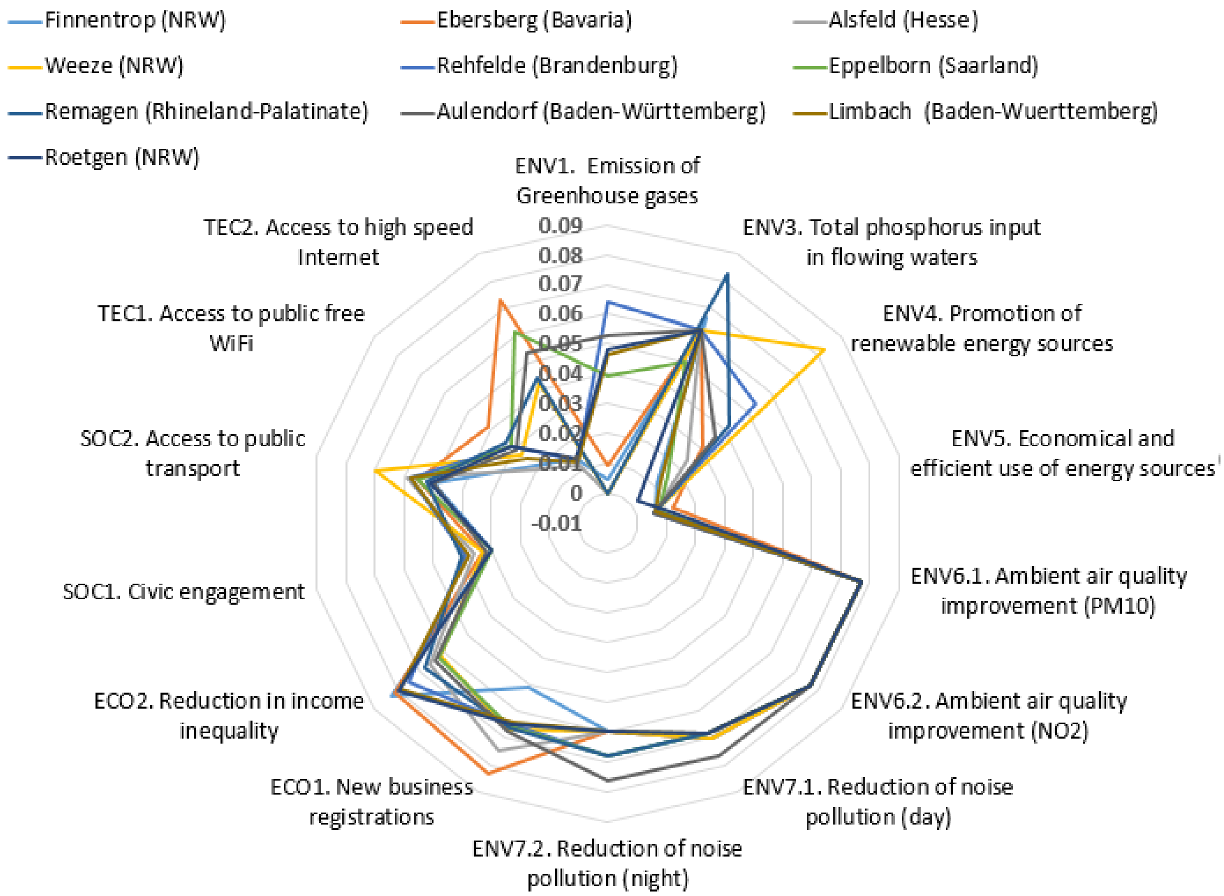

Figure 4. Comparison of the sustainability performance of the examined rural municipalities in Germany based on the resulted score s_i for the selected indicators.

Figure 5, depicts a visual comparison of the sustainability performance of the selected municipalities in Germany using a bar chart. The comparison is based on the final score (S), which is derived by aggregating the resulted score s_i for multiple indicators (c.f. Eq. 5) assessing the sustainability of each municipality. Therefore, S is a single value that summarizes the overall sustainability performance of a rural municipality across economic, social, ecological, and technological dimensions.

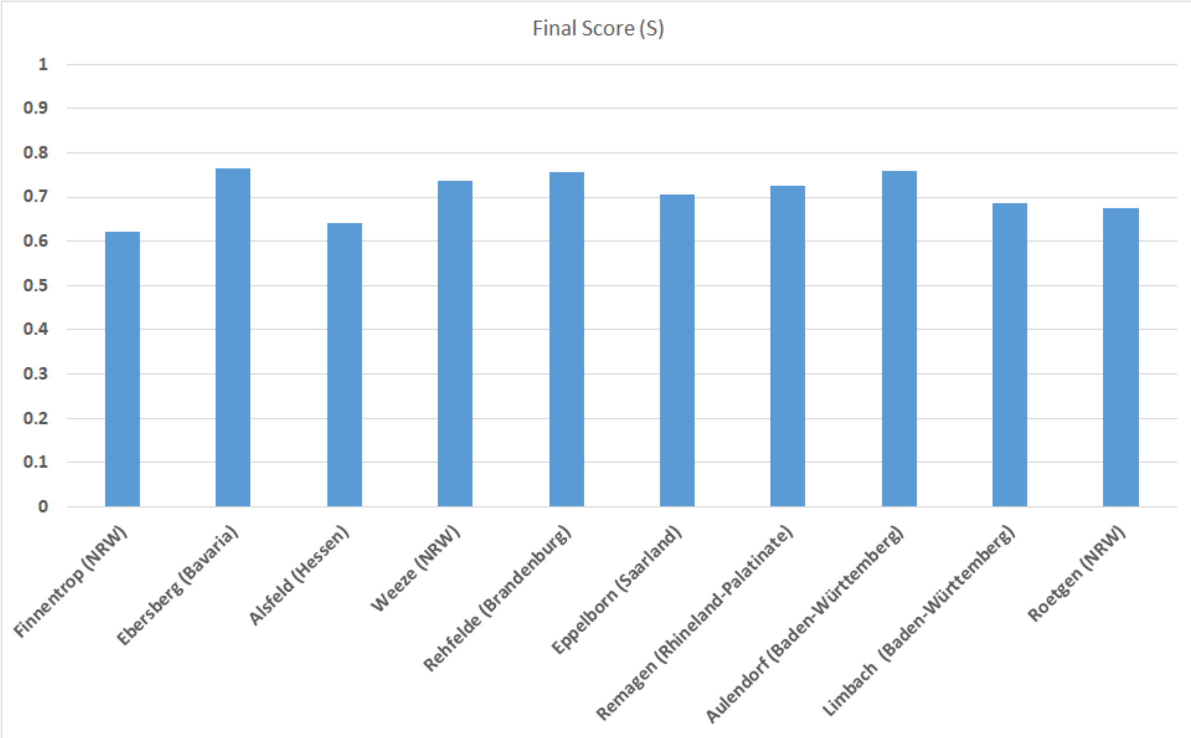

Figure 5. Comparison of the sustainability performance of the selected rural municipalities in Germany based on the aggregated final score (S).

4.5 Discussion

The radar charts in the previous figures summarize and compare the sustainability performance of the individual municipalities. The measurement scales of the indicators are in scale of 0 to 1, and 1 indicates the optimal target value. Comparing the two scenarios with each other shows that the most helpful approach is to compare the sustainability performance of the municipalities within each state against the defined benchmark. This is because each state has a different benchmark, and these state-defined benchmarks for some indicators may also differ compared to the state's sustainability strategies.

The evaluation and assessment of the sustainability performance of rural municipalities open a discussion on several issues. First and most importantly, the data available to measure and evaluate the performance of rural municipalities in Germany is relatively poor. Most databases and sustainability reports considered are updated only every five years and do not capture the performance of rural municipalities in particular too well. This limitation is not unique to our study but is a common challenge encountered in similar research on rural municipalities, indicating that this is a widespread challenge within the field (Benedek et al., 2021; López-Penabad et al., 2022; Rodrigues and Franco, 2020; Frare et al., 2020; Hatakeyama, 2018).

Second, the results obtained from different scenarios compare the performance of the selected municipalities with the best practice. This can encourage regulatory decision-makers and authorities to quickly and systematically review and evaluate the sustainability performance of their entities of interest and compare it with the highest achieved values. Consequently, rural communities can identify their strengths and weaknesses. However, our approach does not show any percentage progress compared to recent years, but only a snapshot of the current sustainability performance of the selected municipalities according to their latest published data similar to other well-known SDG index and dashboard providers (Sachs et al., 2019)

Although the selected sets of indicators is comprehensive, they are not specifically designed for the rural level. Thus, some economic or environmental dependencies might be identified when monitoring the municipalities or some level of customization may be necessary to account for specific country or regional characteristics. For example, if there is no river near the observed municipality, then the indicator for phosphorus in flowing water is not included. In rural areas with fewer than ten thousand residents, the registered businesses per year may not be included. The main reason is that this indicator counts the number of newly registered businesses per ten thousand inhabitants, and so if the rural municipality has below this population, then the results will not be accurate.

Finally, the normalization approach based on the quantitative data is more operational than the other approaches. Since our normalization method is conducted according to the current sustainable development goals, it can be modified regarding new regulations and policies, and other reasonable normalization methods can be developed. Therefore, the proposed approach is helpful to compare the sustainability performance of both rural and more aggregate (e.g. country, state, federal) levels.

4.6 Conclusion and policy implications

For the evaluation and assessment of the sustainability performance of rural municipalities, a clean and readily available dataset that announces the performance of rural municipalities is essential. Regularly updated databases and annual sustainability reports can make the benchmarking approach more dynamic, reliable and feasible for implementation. Thus, the role of dataset creation in the pursuit of sustainability benchmarking needs to be considered further. Therefore, future research should aim to address this limitation by exploring ways to obtain and incorporate historical data, thus enabling a more comprehensive and longitudinal assessment of the sustainability performance of rural municipalities to track their progress over time. Additionally, better data can be obtained by conducting large-scale surveys, which would provide a more extensive and detailed understanding of the indicators and factors influencing sustainable development in these municipalities.

Our study does not aim to provide a definitive representation of all rural municipalities in Germany, but rather to contribute valuable insights into the sustainability performance of selected rural areas. By conducting a detailed analysis of these specific cases, we can identify key challenges and opportunities unique to rural communities and develop targeted strategies for a sustainable development. Our research serves as a starting point for further investigations in this important field.

The findings of our study have important theoretical and practical implications for the field of sustainability assessment in rural municipalities. From a theoretical perspective, this study contributes to the existing literature by proposing a novel sustainability benchmarking system specifically tailored for rural areas. By incorporating dimensions such as the ecological, economic, and technological ones as key performance indicators (KPIs), the study offers a comprehensive framework for evaluating the sustainability performance in rural municipalities. Additionally, the recognition of digitalization as a crucial aspect of societal transition adds a new dimension to sustainability assessment. The methodological advancements in indicator selection, refinement, and filtering criteria enhance the rigor and validity of the benchmarking process.

Moreover, the explicit consideration of data availability, measurability, comprehensibility, comparability, and reliability criteria addresses the challenges associated with sustainability assessments in rural contexts. This contributes to the methodological advancement of sustainability benchmarking and provides a valuable reference for future research in similar settings. From a practical standpoint, the developed sustainability benchmarking system has several implications for rural municipalities and relevant stakeholders. Firstly, it offers a practical tool for rural municipalities to assess and monitor their sustainability performance. By identifying strengths and weaknesses across different dimensions, municipalities can prioritize their sustainability efforts and allocate resources effectively.

Overall, the adopted methodology of aggregating indicators, normalizing values, and deriving a single score enables us to assess the sustainable performance of municipalities and highlight variations among them. Our findings can inform policy-making and decision-making processes in rural areas. The identified dimensions and indicators can guide the development of targeted strategies and interventions to enhance sustainability in rural communities. Policymakers can utilize the benchmarking results to design policies, programs, and initiatives that address the specific sustainability challenges faced by rural municipalities. Lastly, the use of radar charts as a graphical tool for visualizing sustainability performance enables effective communication and knowledge sharing among various stakeholders. The clear presentation of data in radar charts facilitates the understanding of sustainability gaps and areas and scope for improvement. This promotes collaboration and the exchange of best practices among rural municipalities, fostering a collective effort towards sustainable development.

Appendix 2

Table 5. 83 Indicators used to assess the sustainability performance of rural municipalities in Germany.

No.	Indicator
1	Emission of greenhouse gases (GHG)
2	Promotion of renewable energy sources
3	Economic and efficient use of energy sources
4	Ambient air quality improvement
5	Total phosphorus input in flowing waters
6	Reduction of noise pollution
7	New business registrations
8	Reducing income inequality
9	Access to public free WiFi
10	Access to high-speed Internet
11	Population with access to electricity
12	Energy intensity in terms of primary energy and GDP
13	International flows in support of clean energy
14	Research in renewable energy production
15	Investment in energy efficiency
16	FDI for infrastructure and technology to sustainable development services
17	Primary energy consumption
18	Final energy consumption in households per capita
19	Share of renewable energies in gross final energy consumption
20	Share of electricity from renewable energy sources in electricity consumption
21	Heat consumption from renewable energies
22	Proportion of bodies of water with good ambient water quality
23	Amount of water- and sanitation-related activities and programs
24	Proportion of local communities participating in water and sanitation management
25	Proportion of domestic and industrial wastewater flow safely treated
26	Proportion of informal employment in total employment, by sector and sex
27	Material footprint per capita, and per unit of GDP
28	Domestic material consumption per capita, and per unit of GDP
29	Proportion of population covered by a mobile network, by technology
30	Proportion of small-scale industries in total industry value added
31	Proportion of small-scale industries with a loan or line of credit
32	CO_2 emission per unit of value added
33	Number of cities with regional development plans that respond to population dynamics
34	Number of cities with regional development plans that ensure a balanced territorial development
35	Number of cities with regional development plans that increase local fiscal space
36	Proportion of population with convenient access to public transport
37	The agriculture orientation index for government expenditures
38	Amount of fossil-fuel subsidies per unit of GDP (production and consumption)
39	Proportion of domestic budget funded by domestic taxes
40	Fixed Internet broadband subscriptions per 100 inhabitants, by speed

Table 5. continued.

No.	Indicator
41	Proportion of individuals using the Internet
42	Population unable to keep home adequately warm
43	Greenhouse gas emissions intensity of energy consumption
44	Investment share of local GDP
45	Average CO_2 emissions per km from new passenger cars
46	Value added in environmental goods and services sector
47	Greenhouse gas emissions intensity of energy consumption
48	Estimated soil erosion by water
49	Official development assistance as a share of gross national income
50	Young people neither in employment nor in education and training
51	Employment rate
52	Population covered by the Covenant of Mayors for Climate and Energy signatories
53	Emissions of air pollutants (SO_2, NO_x, NH_3, NMVOC and $PM_{2.5}$)
54	Gini income coefficient after social transfers
55	Nitrate in groundwater
56	Number of people gaining access to drinking water
57	Final energy consumption in freight transport
58	Species diversity and landscape quality
59	Proportion of homes using smart home monitoring systems
60	Percentage of electric vehicles
61	Number of public EV charging stations
62	Number of recharges at EV charging stations
63	Foreign direct investment, net inflows
64	Fossil fuel energy consumption (% of total)
65	Investment in energy with private participation
66	Renewable internal freshwater resources, total (billion cubic meters)
67	Firms experiencing electrical outages (% of firms)
68	Start-up procedures to register a business
69	Time required to get electricity (days)
70	Time required to start a business (days)
71	Investment in water and sanitation with private participation
72	Ease of doing business rank
73	Tax revenue (% of GDP)
74	Total tax and contribution rate (% of profit)
75	Research and development expenditure (% of GDP)
76	Imports of goods and services (% of GDP)
77	Energy imports, net (% of energy use)
78	Population density (people per square km of land area)
79	Wage and salaried workers (% of employment)
80	Unemployment rate (% of total labor force)
81	Public private partnerships investment in ICT
82	Fixed telephone subscriptions (per 100 people)
83	Territorial protection

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