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Technologies for Demand-Side Flexibility Within a Just Energy Transition: A German Energy Poverty Perspective

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"There is no such thing as a single-issue struggle
because we do not live single-issue lives."

Audre Lorde

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Abbreviations

AI	Artificial Intelligence
CO_2	Carbon Dioxide
EEG	Erneuerbare-Energien-Gesetz
ETS II	EU Emissions Trading System II
GDP	Gross Domestic Product
IoT	Internet of Things
kWh	Kilowatt-hour

Symbols

κ	Cohen's Kappa coefficient

Abstract

Amidst the progressing energy transition accompanied by the expansion of renewable energy sources and the electrification of energy services, demand-side flexibility is gaining increasing significance for private households. Through market signals, they are incentivized to adjust their consumption according to the current availability of energy in the system. This trajectory is accompanied by the dissemination of technologies for demand-side flexibility which bear the potential to provide flexibility to the energy grid without manual interference from household members. While more affluent households are gradually adopting said technologies, households at risk of energy poverty tend to lack access to them. Applying an energy justice perspective, the research presented twenty injustices associated with the current access of households at risk of energy poverty to technologies for demand-side flexibility. Through a mixed-methods approach encompassing expert interviews and a complementary online survey based on a case study of the German Energiewende*, the results illustrated that the expansion of technologies for demand-side flexibility yields injustices for households at risk of energy poverty beyond the financial cost of these technologies but might instead further exacerbate their risk of energy poverty or exclude them from the energy transition altogether. This represents a clear argument to decrease access barriers for these households to technologies for demand-side flexibility. As such, the research invites stakeholders such as the government, private sector, but also landlords and landladies to incorporate justice considerations into their decision-making processes about digital technologies in the energy sector.*

1 Technologies for Demand-Side Flexibility: An Emerging Focus in the Energy Transition

This research addresses the intersection of energy justice and demand-side flexibility from the perspective of households at risk of energy poverty in the context of Germany. A thorough understanding of this research background necessitates a brief introduction to the energy transition and its key characteristics. With the majority of energy still being sourced from fossil fuels (Olabi & Abdelkareem, 2022), the energy sector accounts for over 38 % of the carbon dioxide (CO_2) emissions worldwide, far exceeding any other economic sector (Crippa et al., 2021). Since the increase of atmospheric carbon dioxide is the main driver of global warming, the transformation of fossil fuels into electricity and heat significantly contributes to climate change (Saint Akadiri et al., 2020). The energy transition represents a central solution thereof as it typically entails a shift away from traditional, high-carbon fossil fuels towards low-carbon renewable energy sources (Tian et al., 2022). Signed by 196 parties, the Paris Agreement and the German *Energiewende* (energy transition) initiative are two of the numerous supranational and national endeavors targeted at a decrease of emissions, thereby implying a decarbonization of the energy sector (Savaresi, 2016; Wiese et al., 2022).

Yet, the energy transition also encompasses central challenges. As opposed to traditional energy sources, renewable energy is generated in a more distributed, decentralized, small-scale, and varying manner (Olabi & Abdelkareem, 2022). Consequently, the available supply in the energy grid is subject to increasing fluctuations and uncertainty (R. Wang et al., 2014). Moreover, the electrification of energy services results in a growing energy demand, particularly during peak times (Bellocchi et al., 2020; Powells et al., 2014). To account for the resulting peaks and troughs of both energy supply and demand, the energy transition is accompanied by the gradual introduction of digital technologies (Küfeoğlu et al., 2019).

Amidst the energy transition, a new area of research at the intersection of technology and social sciences has emerged in recent years (Sovacool & Dworkin, 2015). As a modern branch of environmental justice, the concept of energy justice is centered around the notion that transitions inevitably produce winners who profit from the resulting opportunities as well as losers who bear the associated burdens and lack access to such opportunities (Carley & Konisky, 2020). This dichotomy illustrates that some parts of the society are more affected by the energy transition than others, emphasizing the significance of incorporating inclusivity and distributional considerations into decision-making processes around the energy transition. This is closely related to the notion of energy poverty which addresses the unequal access "to adequate, affordable, reliable, high-quality, safe, and environmentally friendly energy services" (Kopatz et al., 2010, p. 7).

1.1 Problematization and Research Gap

The problematization on which this research builds emerges at the juncture of the increasing dissemination of digital technologies in the energy sector and energy justice considerations. For private households, the energy transition is accompanied by encouragements to alter their use of energy. Through market signals, they are increasingly incentivized to shift their energy consumption to times where supply is abundant and demand is scarce to balance the load on the grid, an ability commonly referred to as demand-side flexibility (D'Ettorre et al., 2022). Consequently, among the widespread adoption of demand-side flexibility, energy bills are increasingly determined by how and when, not only how much, energy a household consumes (Yule-Bennett & Sunderland, 2024).

Approaching this notion from an energy justice perspective, POWELLS & FELL (2019) acknowledge that the ability of households to contribute to demand-side flexibility differs significantly. Apart from a household's financial resources, their flexibility capital is a central factor which determines the way in which a household is affected by demand-side flexibility. It describes the ability to shift energy use in time, space, intensity, or energy sources, and is determined by factors such as work, digital literacy, and electric loads, the authors outline. Said flexibility capital can be either technology- or socially-derived. The former describes the utilization of technologies to manage demand-side flexibility, whereas socially-derived flexibility capital refers to the manual adaptation of daily practices. Due to the investment costs associated with these technologies, the degree of households' technology- or socially-derived flexibility capital depends on their affluence. Households with fewer financial resources and with less flexibility capital experience an increased tension between comfort and energy cost and are at an elevated risk of energy poverty. Hence, amidst the current progress of the energy transition, some households, typically more affluent ones with higher energy loads, already possess technologies for demand-side flexibility, whereas others do not (Powells & Fell, 2019).

From a mere technical energy systems perspective, this is reasonable as those households offer more flexibility capital to the grid. From an energy justice perspective, however, this trajectory might be associated with unintended consequences. Building on the notion of POWELLS & FELL (2019), the potential injustices that are accompanied by the expansion of technologies for demand-side flexibility for households already at risk of energy poverty remain unclear. More precisely, little is known about the ways in which they currently contribute to demand-side flexibility. Furthermore, amidst the increasing uptake of technologies for demand-side flexibility from more affluent households, it is underexplored whether the access to such technologies for demand-side flexibility is related to changes in their energy consumption behavior which might ultimately affect their ability to participate in the energy transition. Henceforth, this phenomenon is referred to as spillover effects. It becomes evident that an energy transition in which more affluent households gradually adopt technologies for demand-side flexibility while households at risk of energy poverty do not stimulates energy justice considerations.

This particularly applies to the case of Germany whose *Energiewende* initiated by the government in 2000 is regarded as one of the furthest progressed energy transitions globally (World Economic Forum, 2023). Amidst the country's gradual expansion of renewable energy sources and the introduction of technologies for demand-side flexibility, the concept of energy poverty has only recently arrived on the scientific and public agenda (Bode, 2022). As of now, scientific contributions addressing energy poverty are scarce; the intersection of digital technologies and energy poverty remains fully underexplored in the German context. Hence, the advanced nature of Germany's energy transition paired with the scarce discourse around energy poverty serves as the basis on which this research builds. The incorporation of the previously outlined injustices for households at risk of energy poverty in the decision-making process of Germany's energy policies is central to pave the way for a just energy transition. Moreover, the country's swiftly progressing energy transition leaves a limited time frame for the incorporation of evidence-based policies targeted at the inclusion of households at risk of energy poverty.

1.2 Research Goal and Research Questions

Against this background, the overarching research goal is to expand the discourse around the injustices associated with the current access of households at risk of energy poverty to demand-side flexibility in the context of Germany. To serve as a basis for energy decision-making among different stakeholders, these injustices are intended to be multifaceted, empirical, and future-oriented. The first step thereof is to enhance the currently scarce academic discourse on energy poverty in the German context by outlining the contribution of households at risk of energy poverty to demand-side flexibility. Furthermore, to identify potential injustices in the longer term, the research aims to assess the spillover effects on households' energy consumption behavior associated with the access to technologies for demand-side flexibility.

To adequately address and consolidate this research goal, the following main research question was formulated: What injustices are associated with the current access of households at risk of energy poverty to technologies for demand-side flexibility? Furthermore, the following two sub-research questions were identified to holistically answer the main research question:

1. In what ways are households at risk of energy poverty currently contributing to demand-side flexibility?
2. What spillover effects does the access of households to technologies for demand-side flexibility have on their energy consumption behavior?

Given the previously outlined research questions, the remainder of this paper is structured as follows. The subsequent chapter introduces the existing body of scientific literature on which this research builds. Chapter 3 provides an outline of the theoretical framework applied within this research, followed by the methodology. The fifth chapter presents central legal and administrative decisions around the case study on the German *Energiewende* as well as a case-specific historical overview of energy poverty. Structured along the three research questions as well as the theoretical framework, Chapter 6 introduces the research findings. The paper concludes with a discussion as well as a conclusion chapter.

2 Literature Review

The following chapter provides a comprehensive overview of the already existing literature on which this research builds. Apart from providing the reader with a comprehensive research background, the information provided in this chapter served as a foundation for the ensuing data collection and analysis. The literature review was conducted in an iterative approach. Under consideration of the research background, relevant scientific literature on the energy transition, digital technologies in the energy sector, as well as energy justice was studied. In accordance with the previously stated research goal as well as the applied energy justice perspective, the chapter predominantly encompasses scientific contributions in the realm of energy policy literature.

Applying a funnel approach, this served as the basis for presenting the current literature on the intersection of digital technologies, demand-side flexibility, and energy justice. As the research progressed, the literature review was further expanded and adjusted until, at the discretion of the researcher, it adequately mirrored the fundamental concepts relevant in the nexus of this study. The chapter is organized accordingly. After an introduction into concepts related to the energy transition, the literature review sheds light on the existing digital technologies in the energy sector. The second part of this chapter presents an outline of the current energy justice literature including an overview of the types used to distinguish different research strings. Lastly, the connection between energy justice and demand-side flexibility is outlined, concluding with the research gap on which this research builds.

2.1 The Energy Transition

The energy transition is closely rooted in global endeavors to combat climate change. The long-term shifts in global temperatures and weather patterns commonly referred to as climate change are a consequence of the increased levels of atmospheric carbon dioxide predominantly caused by human activities (De Matteis, 2019). The resulting surge in global temperatures bears manifold risks for human and environmental systems (Simpson et al., 2021). Since entering the public debate in the 1980s, ambitious national and supranational agreements to combat climate change have gained momentum in recent years (Falkner, 2016). A central driver of climate change is the steadily rising demand for energy which is still predominantly generated from fossil fuels. The transformation of fossil fuels such as oil, coal, diesel, and natural gas into energy is associated with a significant amount of carbon dioxide emissions and thus directly related to climate change (Dogan & Seker, 2016). Since 1980, global energy consumption has more than doubled, a trend propelled by the forces of population and economic growth (Bilgen, 2014; Energy Institute, 2023).

Committing to take measures to combat climate change, numerous multilateral as well as national agreements have been signed by countries. An overview of such decisions which shaped the trajectory of the German *Energiewende* are further delineated in Chapter 5. Central to this commitment is a fundamental change within the energy sector to meet the rising energy demand while simultaneously limiting its adverse effects on climate change and reduce the dependency on finite fossil fuels. First and foremost, these changes encompass the shift away from traditional sources of energy towards low-carbon alternatives such as solar, wind, hydrogen, and bioenergy (Panwar et al., 2011). As opposed to traditional energy sources, renewable energy is created on a more local level and, particularly with regard to solar and wind power, intermittent and variant in nature (Olabi & Abdelkareem, 2022). An example thereof lies in the growing share of photovoltaic projects which are predominantly owned by domestic consumers, illustrating that the energy generation becomes increasingly distributed, decentralized, and small-scale (Küfeoğlu et al., 2019).

This trajectory is further accelerated by the increasing electrification of everyday life, primarily heating and personal mobility. Since the associated household practices such as working, cooking, and laundry are highly social phenomena, their electrification is accompanied by significant peak demands of energy, particularly in the evening hours (Powells et al., 2014). The mismatch between the increasing share of varying renewable energy supply on the one hand and the fluctuating demand from households and the industry on the other illustrates the growing significance of a future energy system that is still capable of ensuring energy security (Küfeoğlu et al., 2019). Digital technologies play a central role in managing the varying energy supply and demand.

2.1.1 Digital Technologies in the Energy Sector

KÜFEOĞLU ET AL. (2019) state that the digitalization of the energy sector "involves the creation and use of computerized information and processing of the vast amounts of data which is generated at all stages of the energy supply chain" (p. 1). More specifically, the German Association of Energy and Water Industries defines the digitalization of the energy sector as the interconnectedness of applications, business processes, and hardware based on internet technologies using sensors and self-controlling devices (Bundesverband der Energie- und Wasserwirtschaft, 2016, p. 14). Correspondingly, within the scope of this research, digital technologies are understood as applications based on either hardware or software, “but in most cases are a combination of both, so-called cyber-physical systems, which use information and communication technology” (Weigel & Fischedick, 2019, p. 2).

Through their analysis of skill requirements in the United States’ energy sector, LYU & LIU (2021) identify six different emerging digital technologies, namely Artificial Intelligence (AI), Internet of Things (IoT), robotics, big data, blockchain, and cloud computing, with Artificial Intelligence being the most prominent. Moreover, WEIGEL & FISCHEDICK (2019) provide a structured overview of the applications in which the abovementioned digital technologies are applied within the energy sector. This also alludes to the ambiguity of the term digital technologies. While LYU & LIU (2021) rather focus on fundamental, enabling digital technologies used across sectors, WEIGEL & FISCHEDICK (2019) instead approach the notion of digital technologies from the practical application in the energy sector. Coalescing these two approaches, digital technologies according to the structure proposed by LYU & LIU (2021) are outlined successively while simultaneously illustrating their practical application in accordance with WEIGEL & FISCHEDICK (2019). Since the research is predominantly focused on the household level where digital technologies in the realm of robotics are uncommon, this concept was not further delineated.

2.1.1.1 Artificial Intelligence

With regard to the first digital technology, SZCZEPANIUK & SZCZEPANIUK (2023) summarize that Artificial Intelligence “presupposes the ability of computer systems to make inferences modelled on human logic and intelligence” (p. 4). Furthermore, the authors outline a typology of Artificial Intelligence algorithms, as well as six application areas within the energy sector.

The first type, Machine Learning, essentially draws on existing data sets to serve as the basis on which predictions about unknown data are made. Metaheuristics are the second type of Artificial Intelligence algorithms. They represent a method to solve optimization problems for which an optimal solution within a reasonable time span is impossible; the use of these algorithms, however, also does not ensure the identification of a solution at all. Fuzzy Inference Systems represent the last type of Artificial Intelligence algorithms introduced by the authors. In contrast to the classic binary logic which calculates with 0 and 1, Fuzzy Inference Systems are based on a multi-valued logic. Acknowledging the ambiguity of problems in the energy system, elements within these algorithms may partially belong to a set, whereas, in a binary logic, they either belong or do not (Szczepaniuk & Szczepaniuk, 2023).

In line with the different types of Artificial Intelligence, its applications are manifold. The algorithms play, for instance, a central role in advanced smart grid management and renewable energy systems (Bose, 2017). Essentially, smart grids are a central cornerstone towards a demand-based, digitalized energy system. They enable the monitoring of the distributed energy generation as well as demand predictions based on historical energy generation and consumption data (Bayindir et al., 2016). Moreover, AI-based algorithms are deployed for the prediction of future demand patterns, thereby significantly contributing to the management of the energy system (Raza & Khosravi, 2015).

2.1.1.2 Internet of Things

IoT is a worldwide communication infrastructure via the internet that "provide[s] connectivity anywhere, of anything and anywhere between homogeneous objects" (Haseeb et al., 2019, p. 1). More specifically, HOSSEIN MOTLAGH ET AL. (2020) state that the Internet of Things consists of physical objects and elements fitted with sensors, actuators, and processors which communicate with each other to perform tasks. Moreover, the authors present five different components which constitute an IoT platform. The first thereof is the application, depending on the purpose the technology is supposed to fulfil.

Based on the chosen application, suitable devices are identified, among them sensors, actuators, and communication technologies. The former serve to immediately collect and transmit data. In the energy sector, sensors are predominantly used to facilitate decision-making, diagnostics, and optimization processes. Actuators, on the other hand, enable the desired execution of devices within the IoT system. They are predominantly applied in industrial processes for increased energy efficiency. Through IoT gateways, wireless communication systems allow for the exchange of data between sensors. Communication protocols represent the third component of IoT platforms as they permit the sharing of the data collected by the devices with decision-makers. Data storage and data analytics pose the last two components of an IoT platform, enabling the management, analysis, and ultimately decision-making based on the collected data (Hossein Motlagh et al., 2020).

Similar to Artificial Intelligence, the Internet of Things is widely used in different industries. In the energy sector, the application areas range from the industry to smart cities and residential housing. As for the latter, IoT devices play a role in solar storage, electric vehicle charging, and household automation in the context of smart home applications (Ahmad & Zhang, 2021). Constituting a central part of this research's scope, smart home technologies provide "intelligent living environments for daily convenience and comfort" (Zaidan & Zaidan, 2020, p. 142). Services in the nexus of smart home range from the visualization of energy consumption in real time to smart devices for energy efficiency optimization, tariff and consumption optimization, and security systems (Weigel &

Fischedick, 2019). Combined with additional digital technologies in the energy sector, the Internet of Things paves the way for residential smart home energy management systems for automated energy saving (Machorro-Cano et al., 2020).

2.1.1.3 Big Data and Cloud Computing

In light of the previously outlined digital technologies, it becomes evident that the energy system consistently generates, but is also dependent on, large amounts of data. Big data is often characterized as being high in volume, velocity, and variety, typically referred to as the three V's. In this context, volume alludes to the massive amount of data. Variety refers to the different sources from which the data is gathered, whereas velocity describes the speed in which this data is collected (Berger & Doban, 2014).

The smart grid infrastructure, connected with individual households through smart meters, is an essential source of big data. Smart meters are digital electricity meters that allow bidirectional communication between the meter installed in a private household and an energy supplier based on smart metering technology (Wunderlich et al., 2019). Through a smart meter gateway which serves as a communication unit between the smart grid and private households, smart meters enable a remote reading of electricity consumption and greater transparency for consumers. Therefore, the smart meter gateway continuously collects, processes, encrypts, transmits, stores, and analyzes consumption data and measured values (Hellmuth & Jakobs, 2020).

Cloud computing is closely related to the concept of big data as it represents a common solution to handle the massive amount of information associated with it (Ouf & Nasr, 2015). BAEK ET AL. (2015) state that cloud computing, known for its scalability, energy efficiency, and cost saving, "provides computational resources on demands" (p. 1) and thus yields the necessary abilities to manage big data. In the energy sector, cloud computing enables the transmission of huge data sets in a smart grid environment. This lays the foundation for an advanced power system monitoring through analyses such as optimization and forecasting (AL-Jumaili et al., 2023; Zhou et al., 2016).

2.1.1.4 Blockchain

Also referred to as distributed ledgers, a blockchain is a "shared and distributed database that contains a continuously expanding log of transactions in their chronological order" (Andoni et al., 2019, p. 145). Several of these digital transactions are collected into time-stamped blocks which, like a chain, are linked to their predecessors. Instead of trusting on a central authority to ensure the validity of transactions, blockchain relies on distributed consensus algorithms which enable network members to verify transactions themselves. Through this system, distributed ledgers are considered as particularly secure and transparent (Andoni et al., 2019).

Due to these characteristics, blockchain finds its application in an energy system predominantly based on renewables. As WANG ET AL. (2021) explain, the technology lays the foundation for smart contracts. Blockchain enables smart contracts to automatically take decisions from a predefined set of rules and criteria such as the availability of renewable energy and the current energy price (Kirli et al., 2022). However, a prerequisite for smart contracts is an energy system which permits dynamic pricing and thus adjusts the price of energy according to the currently available demand (Dutta & Mitra, 2017). Enabled by blockchain technology, smart contracts on the basis of digital currencies are then used for the secure transaction of data within a smart grid system (Q. Wang et al., 2021).

Dynamic time-of-use tariffs are prominent examples of such smart contracts which build on the blockchain technology to ensure privacy and security (Knirsch et al., 2018; Schletz et al., 2020). In the context of demand-side flexibility, these tariffs are gaining increasing significance. Amidst electricity peak demands, electricity prices substantially increase, potentially even leading to system blackouts (Pallonetto et al., 2016). Since dynamic time-of-use tariffs are characterized by varying electricity prices that depend on the current supply and demand of energy as well as the market price, they incentivize households to adjust their energy consumption patterns accordingly (Nicolson et al., 2018). The means through which said adjustment of energy loads can be achieved vary, ranging from the manual execution by household members to full automation where the need for human intervention is eliminated (Pallonetto et al., 2016).

As previously outlined, digital technologies play a pivotal role in the energy sector and are applied in numerous ways throughout the system and are closely intertwined. The implications associated with these technologies for the energy transition, however, reach far beyond environmental and technological spheres. Rather, the energy transition is accompanied by profound social repercussions which are addressed in the different fields of energy justice.

2.2 Energy Justice

Historically, energy justice is rooted in the environmental justice movement of the United States. As MOHAI ET AL. (2009) illustrate in their conceptual review, environmental justice initially emerged in the context of environmental racism. The latter brought attention to the disproportionate environmental risks people of color and low-income communities face; a matter which appeared on the public agenda through civil rights movements in the early 1980s. As a countermeasure against environmental racism, Bullard (1996) coined the term environmental justice as "the principle that all people and communities are entitled to equal protection of environmental and public health laws and regulations" (p. 493). Environmental justice hence connects the concepts of "environmental issues and social justice" (Figueroa, 2022, p. 427) previously treated as distinct topics.

Since the 1980s, the framing and scope of environmental justice has expanded beyond the United States. While early environmental justice considerations mainly tackled issues of distribution, the discourse gradually started to incorporate procedural and recognition aspects in the early 2000s (Walker, 2009), three concepts later on also applied in energy justice research. Environmental justice yields implications both on a national and global scale, particularly considering the implications associated with climate change, and serves as a starting point for a plethora of research strings emerging from environmental risks and access to resources. Sparked by the broader discourse on environmental inequality and the progressing energy transition, energy justice appeared on the social science research agenda.

Scientific contributions directly dedicated to energy justice surfaced in the early 2010s, aiming, as Jenkins et al. (2016) recognize, to employ notions of justice to energy policy, energy production and systems, energy consumption, energy activism, energy security, and climate change (p. 175). Congruently, the authors perceive energy justice as an interdisciplinary field, incorporating perspectives from "business, geography, political science, legal studies, philosophy, and environmental studies" (p. 175).

In accordance with the notion of environmental justice, Sovacool et al. (2017) define energy justice as an "energy system that fairly distributes both the benefits and burdens of energy services, and one that contributes to more representative and inclusive energy decision-making" (p. 1). Correspondingly, Carley & Konisky (2020) introduce the concept of energy justice by acknowledging that the energy transition inevitably produces winners who benefit from cleaner sources of energy, decreased emissions due to the shift away from fossil fuels, and the employment of innovation opportunities which accompany it. Simultaneously, the energy transition produces losers bearing the burdens or lacking access to such opportunities.

Based on the awareness for the growing number of scholars advocating for the incorporation of energy research into policymaking, Galvin (2019) perceives energy justice research as an approach towards a "joined-up ethical framework" to discuss "issues of fairness between people, on local and global scales, in relation to energy supply, production and consumption" (p. 176). This corresponds with McCauley et al.'s (2019) appeal to incorporate "questions of energy justice [into the energy transition] to ensure that policies, plans and programs guarantee fair and equitable access to resources and technologies" (p. 916). Therefore, SOVACOOL ET AL. (2016) propose an energy justice framework consisting of eight principles to support energy policies which served as the theoretical framework of this research and is further delineated in Chapter 3.

As such, energy justice equally serves as a conceptual, analytical, and decision-making tool, SOVACOOL & DWORKIN (2015) explain. While the former enables a philosophical and ethical point of view, energy justice as an analytical tool particularly addresses energy researchers aiming to find solutions for problems in the energy system. The concept can also be applied to aid the decision-making of energy planners. In the context of this research, energy justice is predominantly treated as an analytical and decision-making tool.

Similar to the environmental justice literature, energy justice research has brought forth several conceptualizations, primarily distributional, recognition, and procedural justice coined by MCCAULEY ET AL. (2013) as the triumvirate of tenets. JENKINS ET AL. (2016) appeal for the inclusion of each of these tenets into energy policies under consideration of both energy production and consumption in a global, holistic manner. To further conceptualize energy justice, the triumvirate of tenets as well as further types of energy justice are introduced hereinafter, both generally and in the nexus of digital technologies in the energy sector.

2.2.1 Distributional Justice

Distributional justice is rooted on the fundamental inequalities of the energy system in terms of the location of energy generation and the corresponding access to energy (Sovacool et al., 2016). In this context, distributional justice, less commonly also referred to as distributive justice (Sovacool & Dworkin, 2015; Sovacool et al., 2019; Pellegrini-Masini et al., 2020), aims at the identification where energy injustices emerge (Jenkins et al., 2016). More specifically, it pertains to "the distribution of costs and benefits of energy supply and consumption – who pays, who can afford to pay, what benefits they get and what disadvantages they suffer" (Galvin, 2019, p. 176). Strikingly, energy is perceived as a benefit in these definitions – or, more generally, a good. Yet, energy in itself is not a good; rather, it serves as a means through which other goods are acquired, a notion on which the term "energy services" builds (Jones et al., 2015, p. 19). In the nexus of households, these energy services include, but are not limited to, heating, cooking, cooling, and lighting (Sovacool, 2011).

In their conceptual review, JENKINS ET AL. (2016) distinguish between the distribution of ills for electricity consumers and the re-distribution of benefits with regard to distributional justice. The distribution of ills entails a financial component in the sense that the energy transition bears the risk of imposing relatively higher costs on those with a lower income. Furthermore, it involves a spatial element resulting from the increasingly distributed and potentially uneven energy supply amidst an energy system based on renewables. This, in turn, exemplifies the association between distributional justice and geographical considerations. Authors such as BOUZAROVSKI & SIMCOCK (2017) expand on the spatial dimension of energy justice, acknowledging that the access to energy is a geographically dependent matter.

The distribution of ills also demonstrates that distributional justice has a social dimension since the access to energy services within society differs, particularly depending on individuals' economic situation. This is closely intertwined with the concept of energy poverty. Notably under the term fuel poverty, energy poverty originated from the United Kingdom in the 1970s. WALKER & DAY (2012) conceptualize it as an injustice which involves the "compromised ability to access energy services and thereby to secure a health[y] living environment" (p. 69). Correspondingly, KOPATZ ET AL. (2010) define energy poverty as the lack of access to adequate, affordable, reliable, high-quality, safe, and environmentally friendly energy services for human development (p. 7). While energy poverty has a decade-long Anglo-Saxon history in research and policymaking, the term only recently arrived on the scientific and public agenda in Germany; a consensus on an official national measure for energy poverty has yet to be reached (Heindl, 2015; Schultz, 2018).

With regard to the abovementioned re-distribution of benefits, JENKINS ET AL. (2016) approach distributional justice from the opposite angle. Here, the authors raise questions as to whether the unfair spread of benefits caused by the energy transition creates injustices as well, and whether the re-distribution of such benefits constitutes to justice.

2.2.2 Recognition Justice

In the triumvirate of tenets by MCCAULEY ET AL. (2013), recognition justice represents the third tenet. More recently, scholars perceive recognition justice as the second and procedural as the final tenet which builds on the others (Jenkins et al., 2016; McCauley, 2018). Hereby, the researchers acknowledge that first, injustices must be identified before those affected can be recognized. Only then, suitable strategies to address the injustices can be discerned (Bartiaux et al., 2018). Following this structure, recognition justice is presented as the second tenet, advocating for equal respect and equal rights across groups (Walker & Day, 2012).

An absence of recognition can manifest differently, ranging, as MCCAULEY ET AL. (2013) describe, from "forms of cultural and political domination" to "insults, degradation and devaluation" (p. 3). Correspondingly, JENKINS ET AL. (2016) distinguish between the three injustices non-recognition, cultural domination, and disrespect. Non-recognition is associated with the failure to acknowledge specific groups and their energy needs, resulting in a lack of information about marginalized social groups. Here, the authors draw the connection to the United Kingdom's legacy of energy poverty in relation to the recognition of specific energy needs among social groups. Cultural domination and disrespect are discernible as the misinterpretation of opponents' objections against energy transition programs; an approach which potentially impedes the identification of feasible compromises (Jenkins et al., 2016). Similar to the previous tenet, these conceptualizations in the nexus of recognition justice have manifested in the Anglo-Saxon context. Due to the lack of scientific research, the extent to which these concepts find application in Germany remains, however, underexplored.

2.2.3 Procedural Justice

As formerly justified, procedural justice ensues recognition justice since the recognition of any stakeholder is required to ensure their non-discriminatory and equitable participation in decision-making (Pellegrini-Masini et al., 2020). Procedural justice represents, thus, the third of the triumvirate of tenets. Essentially, procedural justice appeals for the incorporation of all groups into the decision-making process (McCauley et al., 2013). JENKINS ET AL. (2016) remark that procedural justice is targeted at providing strategies for the remediation of energy injustices. Appeals for procedural justice thus clearly contradict with features of modern energy systems characterized by what JONES ET AL. (2015) describe as "a form of technocratic authoritarianism" and rigidity as a result of path dependency and deliberate industry design (p. 149 f).

BELL & ROWE'S (2012) definition of procedural justice entails "fairness in the process of decision-making and policy-making" (p. 2). Correspondingly, SIMCOCK (2016) presents three dimensions of procedural justice according to which the fairness of a decision-making process is determined, namely inclusion, responsibility, and influence. A relevant aspect regarding the former is that those affected by a decision should also be involved in reaching it. Complementary, JENKINS ET AL. (2016) name local knowledge mobilization, greater information disclosure, and better institutional representation as three mechanisms of inclusion. The first thereof is based on the perception that including knowledge and discourse in decisions significantly impacts policies. Secondly, procedural justice requires meaningful participation, impartiality, full information disclosure by the government and industry, as well as appropriate engagement mechanisms. The last mechanism, better institutional representation, emphasizes that the unequal representation of gender and ethnic minorities in the government and the industry is a motor for unjust decision-making.

Returning to SIMCOCK'S (2016) dimensions, the second one raises questions about the responsibility of actors to ensure said inclusion. According to the author, the last dimension, influence, refers to the different degrees to which participants can shape outcomes, ranging from a mere spectator to a direct decision-maker.

2.2.4 Beyond the Triumvirate of Tenets

Even though the triumvirate of tenets holds a prominent place in energy justice literature, there are various other types complementary to the three. Cosmopolitan justice, for instance, emphasizes the global nature of today's energy system in the context of environmental concerns and, ultimately, climate change. Hence, cosmopolitan justice provides the foundation for a multitude of cross-cultural research areas closely intertwined with fundamental justice considerations and their global scope as well as the role of morality and political responsibility (Jones et al., 2015).

Given the geographical component in both cosmopolitan and spatial justice yields certain analogies; a main difference between the two disciplines is, however, their scope. While spatial justice acknowledges that the access to energy services may vary within a city, region, or country, cosmopolitan justice investigates energy justice from a global, cross-border point of view. Simultaneously, the discourse around cosmopolitan justice and its geographical element acts as a starting point to consider whether energy justice also has a temporal component. Apart from the long-term effects of climate change and the energy needs of future generations, the temporality of energy justice also sparks the discourse around the availability and affordability of energy services tomorrow (Jones et al., 2015; Galvin, 2019).

HEFFRON & MCCAULEY (2017) introduce restorative justice as a method to either repair existing injustices or prevent them altogether. Therefore, the authors call for the holistic incorporation in theory, expressed through the triumvirate of tenets, on a global scale through cosmopolitan justice, and practically, with the energy justice framework further delineated in Chapter 3. The idea behind restorative justice is to take the potential harm for people, society, and nature into account prior to decision-making, thus ensuring policymakers' careful deliberation about potential outcomes (Heffron & McCauley, 2017).

Moving away from the fundamental typology of energy justice, scientific contributions at the intersection of energy justice and digitalization have gained momentum within recent years. Here, energy justice has been extensively assessed in the context of smart grids, but also the digital economy, Artificial Intelligence, and automated driving (Hillerbrand et al., 2021; Milchram et al., 2018, 2020; Noorman et al., 2023). Another topic closely related to the digitalization of the energy sector recently addressed by scholars is demand-side flexibility which is, due to its relevance in the scope of this paper, further delineated subsequently.

2.3 Energy Justice and Demand-Side Flexibility

Demand-side flexibility is a concept closely related to demand-side management. Under the latter, approaches towards the incorporation of renewable energy sources into the energy system while simultaneously ensuring security, reliability, and resilience by managing demand-side activities are summarized (Stavrakas & Flamos, 2020). In light of the increasing share of renewables complicating the continuous system balance of the energy grid, demand-side management aims to ensure the "real-time control of distributed energy sources" (Lampropoulos et al., 2013, p. 1). Here, several approaches are distinguished, loosely classified into strategic load growth, energy efficiency, and demand response; demand-side flexibility builds on the latter (Lampropoulos et al., 2013).

ADUDA ET AL. (2016) conceptualize demand-side flexibility as "the ability of demand side installations to respond to power systems requirements for ramping up or down using on-site storage capabilities, increasing or reducing electricity consumption patterns while maintaining acceptable indoor comfort bandwidth" (p. 147). In other words, demand-side flexibility utilizes different methods and digital technologies to adjust the current demand to the available supply; an endeavor in which not only industrial, but increasingly also residential end consumers play a crucial role. For the latter, being flexible means "having the ability to shift energy use in time and space, or through changes in intensity or vector, such as switching from gas to electricity" (Powells & Fell, 2019, p. 56) to reduce peak load on the grid. In this context, ADAMS ET AL. (2021) recognize that the "flexibility of energy use is or will be an important and highly priced new economic and security resource within energy systems" (p. 3).

Amidst the progressing energy transition accompanied by the application of new digital technologies as well as the advent of dynamic time-of-use tariffs, the ability to be flexible is increasingly valuable for consumers. Thus, albeit an inherently technical topic, demand-side flexibility also yields far-reaching justice implications. Through their study on 186 households in the United Kingdom, POWELLS ET AL. (2014) conclude that flexible energy use is highly related to social practices, not merely the behavior of individuals. These social practices include, for instance, cooking, eating, and doing laundry. Even more so, the flexibility of these practices varies, depending on daily rhythms and conventions, the authors demonstrate. This illustrates that, by adjusting their social practices, households possess the ability to be flexible, a term coined by POWELLS & FELL (2019) as socially-derived flexibility. In contrast, technology-derived flexibility results from the application of digital technologies, thus not necessitating a change in a household's daily practices.

In accordance with this, POWELLS & FELL (2019) introduce the concept of flexibility capital which is highly dependent on numerous factors ranging from work, social patterns such as digital literacy, household characteristics, and electric loads to gender and wealth. By drawing attention to the interplay between flexibility capital and affluence, the authors acknowledge that the ability of a household to be flexible, either through social or technological means, differs. Those who possess fewer financial resources tend to derive their flexibility through changes in social practices instead of technologies in anticipation of economic rewards, potentially resulting in a decrease of their comfort or convenience, POWELLS & FELL (2019) state. Even more so, particularly those with less flexibility capital and fewer financial resources are confronted with a higher risk of energy poverty and the exclusion from smart energy services (Powells & Fell, 2019). This highly corresponds with WALKER'S (2013) statement that "transitions towards a lower carbon society are likely to have significantly uneven consequences: whilst some people will be able to adopt lower carbon technologies and afford higher energy prices, others will find themselves excluded, or unable to escape the effects of infrastructural lock-in" (p. 182).

Despite POWELLS & FELL (2019) raising awareness of the risks less affluent households face with regard to demand-side flexibility, scientific contributions through an energy justice lens particularly focusing on households already at risk of energy poverty remain scarce. Thus far, the discourse on injustices associated with demand-side flexibility mainly focuses on the varying inability of households to be flexible which is closely related to the unaffordability of technologies for demand-side flexibility for those with fewer financial resources, as well as the resulting distributional effects among society (Jalas & Numminen, 2022; Powells & Fell, 2019; Torriti & Yunusov, 2020; von Platten, 2022; White & Sintov, 2020; Yule-Bennett & Sunderland, 2024). A further injustice both WALKER (2013) and POWELLS & FELL (2019) touch upon is the matter of exclusion.

Against this background, the injustices associated with the current access of households at risk of energy poverty to technologies for demand-side flexibility who, according to POWELLS & FELL (2019), belong to those at highest risk of exclusion from the energy transition, have not been fully assessed yet. As of now, little is known about their current contribution to demand-side flexibility. Even more so, it remains unclear whether households' access to technologies for demand-side flexibility influences their energy consumption behavior and with that, their overall participation within the energy transition, a phenomenon referred to as spillover effects in this paper. If this was the case, the limited access of certain social groups towards such technologies might constitute an injustice beyond financial considerations. Due to the comparatively advanced progress of Germany's *Energiewende* paired with the scarcity of scientific contributions addressing energy justice, particularly energy poverty, in the country's context, the research addresses this goal through a case study on Germany.

3 Theoretical Framework

As previously stated, the overarching research goal is to contribute to the discourse around the injustices associated with the current access of households at risk of energy poverty to demand-side flexibility in the context of Germany. To assist the energy decision-making between different stakeholders, these injustices are intended to be multifaceted, empirical, and future-oriented. The first step thereof is to expand the currently scarce academic discourse on energy poverty in the German context by delineating the contribution of households at risk of energy poverty to demand-side flexibility. Furthermore, to identify potential injustices in the longer term, the research aims to assess the spillover effects on households' energy consumption behavior associated with the access to technologies for demand-side flexibility. Correspondingly, the following main research question was identified: What injustices are associated with the current access of households at risk of energy poverty to technologies for demand-side flexibility?

To holistically answer this research question, the following sub-research questions were identified:

1. In what ways are households at risk of energy poverty currently contributing to demand-side flexibility?

2. What spillover effects does the access of households to technologies for demand-side flexibility have on their overall energy consumption behavior?

The following chapter outlines the theoretical framework according to which the research questions were answered. It begins by delineating central concepts used in the scope of this research. Consecutively, the energy justice framework which was adjusted to serve as the paper's theoretical framework is introduced.

3.1 Establishing a Common Terminology

The systematic answer to the research questions requires a mutual understanding of the used terminology. This prevents ambiguities and provides a common ground on which the central theoretical framework can be presented. As previously alluded to, the term "technologies" as applied within the research questions can be defined differently, depending on the context. In the scope of this research, technologies for demand-side flexibility are understood as any digital technology in the energy sector which enables, either through manual interventions or automatically, demand-side flexibility.

Furthermore, the expression "households at risk of energy poverty" requires further contextualization. Following the formerly introduced definition of KOPATZ ET AL. (2010), households at risk of energy poverty are operationalized as such that are at risk of being unable to access adequate, affordable, reliable, high-quality, safe, and environmentally friendly energy services for human development. Building on the perception further delineated in Chapter 5 that energy poverty is a complex, multifaceted phenomenon, the households prone to this risk were not further demarcated in advance. Instead, household characteristics contributing to the risk of energy poverty serve as a foundation for establishing the results of the first sub-research question.

3.2 The Energy Justice Decision-Making Framework

The energy justice decision-making framework by SOVACOOL ET AL. (2016) serves as the theoretical framework of this research. As the authors describe, the framework was designed to contextualize core elements of energy justice research which were addressed in Chapter 2 through eight decision-making principles. It is an approach to facilitate the common understanding among researchers, practitioners, and energy consumers when referring to energy injustices. Therefore, SOVACOOL ET AL. (2016) perceive the framework as a means "that can begin to achieve a more just and equitable balance of all the competing aims in energy policy and ensure that the trade-offs that are made in the energy sector are inherently more just and equitable in their societal outcomes" (p. 14).

The framework consists of the principles availability, affordability, due process, transparency and accountability, sustainability, intragenerational equity, intergenerational equity, and responsibility. According to the author's definition, the principle of availability demands that "[p]eople deserve sufficient energy resources of high quality" (Sovacool et al., 2016, p. 14). Affordability emphasizes that "[t]he provision of energy services should not become a financial burden for consumers, especially the poor" (p. 14). Here, SOVACOOL ET AL. (2017) further elaborate that "[a]ll people, including the poor, should pay no more than 10 % of their income for energy services" (p. 687). Due process, on the other hand, appeals that "[c]ountries should respect due process and human rights in their production and use of energy" (Sovacool et al., 2016, p. 14).

Continuing with the eight decision-making principles of SOVACOOL ET AL. (2016), transparency and accountability stresses that "[a]ll people should have access to high quality information about energy and the environment and fair, transparent, and accountable forms of energy decision-making" (p. 14). Sustainability emphasizes that "[e]nergy resources should not be depleted too quickly" (p. 14). Intragenerational equity requires that "[a]ll people have a right to fairly access energy services", whereas intergenerational equity demands that "[f]uture generations have a right to enjoy a good life undisturbed by the damage our energy systems inflict on the world today" (p. 14-15). Lastly, responsibility entails that "[a]ll nations have a responsibility to protect the natural environment and reduce energy-related environmental threats" (p. 15).

Considering the previously outlined principles, it becomes evident that, contrary to the types of energy justice, the energy justice framework provides a more practice-oriented approach to identify and address injustices. As such, the framework not only facilitates the operationalization of the eight underlying principles, but it also enables an expansion through further principles if needed, as well as the omission of principles unsuitable for the research background. Given its practice-oriented character, the energy justice framework also yields the potential to convey injustices in a straightforward and structured manner. While it was initially considered to use the philosophical notion behind the triumvirate of tenets (Jenkins et al., 2016) consisting of distributional, recognition, and procedural justice as the theoretical framework, the energy justice decision-making framework appeared to be the more suitable choice due to these reasons.

In the context of this research, the energy justice framework served three purposes. First, it ensured that the topic of demand-side flexibility was approached from an energy justice perspective. Secondly, the framework provided structure for both the data collection, particularly the successively outlined interviews, as well as for the data analysis. Lastly, the energy justice framework functioned as a skeleton according to which the research questions were answered, particularly the third sub-research question whose results directly mirror the structure of the energy justice framework.

To achieve these purposes, the eight decision-making principles were operationalized according to the research background. The first principle, availability, was adjusted by stating that households deserve sufficient energy resources of high quality and the possibility to use technologies for demand-side flexibility in their homes. In the context of this research, affordability entails that the provision of energy services and technologies for demand-side flexibility should not become a financial burden for households and the financial rewards resulting from demand-side flexibility should be fair. Due process demands that all stakeholders and decision-makers should respect due process and human rights in their production and use of energy, including the production and use of technologies for demand-side flexibility.

The third principle, transparency and accountability, was slightly refined by stating that households should have access to high quality information about their energy consumption and the environment and fair, transparent, and accountable forms of energy decision-making. Sustainability highlights that energy resources should be used sparingly, and energy should be generated from renewable energy sources. Intragenerational equity demands that all households, irrespective of gender, wealth, ethnicity, and living situation have a right to fairly access energy services and technologies for demand-side flexibility. The principle of intergenerational equity was expanded by stating that future generations have a right to enjoy a good life undisturbed by the damage our energy systems inflict on the world today and that they have a right to fairly access energy services and technologies for demand-side flexibility. Lastly, responsibility requests that all stakeholders and decision-makers have a responsibility to protect the natural environment and reduce energy-related threats while ensuring that households are granted a level of agency about their use of energy services and technologies for demand-side flexibility.

Table 3.1 provides an overview of the eight principles previously outlined in conjunction with the original definition by SOVACOOL ET AL. (2016) as well as the slightly adjusted principles operationalized for this research.

Table 3.1: Overview of the Operationalized Energy Justice Decision-Making Framework based on SOVACOOL ET AL. (2016)

Principle	Definition from SOVACOOL ET AL. (2016)	Definition Operationalized for the Purpose of this Research
Availability	People deserve sufficient energy resources of high quality	Households deserve sufficient energy resources of high quality and the possibility to use technologies for demand-side flexibility in their homes
Affordability	The provision of energy services should not become a financial burden for consumers, especially the poor	The provision of energy services and technologies for demand-side flexibility should not become a financial burden for households and the financial rewards resulting from demand-side flexibility should be fair
Due Process	Countries should respect due process and human rights in their production and use of energy	All stakeholders and decision-makers should respect due process and human rights in their production and use of energy, including the production and use of technologies for demand-side flexibility

Principle	Definition from Sovacool et al. (2016)	Definition Operationalized for the Purpose of this Research
Transparency and accountability	All people should have access to high quality information about energy and the environment and fair, transparent, and accountable forms of energy decision-making	Households should have access to high quality information about their energy consumption and the environment and fair, transparent, and accountable forms of energy decision-making
Sustainability	Energy resources should not be depleted too quickly	Energy resources should be used sparingly, and energy should be generated from renewable energy sources
Intragenerational equity	All people have a right to fairly access energy services	All households, irrespective of gender, wealth, ethnicity, and living situation have a right to fairly access energy services and technologies for demand-side flexibility
Intergenerational equity	Future generations have a right to enjoy a good life undisturbed by the damage our energy systems inflict on the world today	Future generations have a right to enjoy a good life undisturbed by the damage our energy systems inflict on the world today and a right to fairly access energy services and technologies for demand-side flexibility
Responsibility	All nations have a responsibility to protect the natural environment and reduce energy-related environmental threats	All stakeholders and decision-makers have a responsibility to protect the natural environment and reduce energy-related threats while ensuring that households are granted a level of agency about their use of energy services and technologies for demand-side flexibility

The operationalized energy justice decision-making framework enabled the data collection and analysis which is presented subsequently.

4 Methodology

The following chapter outlines the methodology on which the research was built, that is, an inductive/deductive, mixed-method single case study of Germany based on expert interviews as well as an online survey. A case study has been chosen since it allows the investigation of a contemporary phenomenon, namely the intersection of energy justice and demand-side flexibility, within a real-life context (Yin, 1992), thus enabling practical insights into an emerging research field. Moreover, YIN (1992) outlines that case studies permit the incorporation of both qualitative as well as quantitative data which fits to the formerly outlined methods chosen for data collection. Lastly, the author acknowledges that case studies, if based on theoretical considerations, can serve as a foundation to derive generalizations. Correspondingly, addressing the research questions through a case study of Germany yields insights which, to an extent, may be transferred into other contexts. Further insights into the country's energy transition relevant in the nexus of this research are accessible under Chapter 5.

The data through which the German case was studied originated from two sources, namely expert interviews as well as a complementary close-ended online survey. Hence, the research applies a mixed-method approach as it combines both a qualitative as well as a quantitative method of data collection (Creswell, 1999). Despite ambiguities in terms of the actual combination of these methods in the literature (Baškarada & Koronios, 2018), mixed-methods studies yield the potential to engage "in research that represents the best of both worldviews" (Guba & Lincoln, 2005, p. 201). Undeterred by their epistemological differences, the combination of qualitative and quantitative methods is particularly suitable for practice-oriented research as is the case in this paper (Brannen, 2005). Furthermore, a mixed-methods methodology was chosen as it enables to corroborate as well as elaborate the findings from the expert interviews through those from the survey (Creswell, 1999).

The use of both qualitative and quantitative data enables an analysis which is characterized by both inductive as well as deductive elements, an approach coined by PROUDFOOT (2023) as an inductive/deductive hybrid analysis. As elaborated successively, the thematic analysis, primarily driven by the qualitative data, builds on previously existing themes which were derived from the theoretical framework. This represents the deductive, top-down approach to the data analysis. Additionally, the research includes inductive, bottom-up elements through the generation of additional themes within the data. These elements, in the case of this research presented as injustices, were derived from the qualitative as well as the quantitative data and synthesized in an iterative manner to develop the finalized set of themes. Thereby, the hybrid inductive/deductive analysis enabled the evaluation and reconceptualization of the theoretical framework against the research background (Proudfoot, 2023).

Apart from the software solutions further delineated in the ensuing subsections of this chapter, two additional tools based on Artificial Intelligence were used throughout the research, the first of which is QuillBot. The website was used to rephrase existing sentences to enhance readability. Furthermore, the natural language processing software ChatGPT based on the GPT-4 architecture was employed to gather an initial overview of qualitative data and structure text segments. Hence, these websites were exclusively used to assist the writing process.

Under these considerations, the following subchapters outline the methodology applied in this paper. The qualitative part of the research is introduced first, according to the chronological order in which the methods were employed. After outlining the approach towards the preparation and execution of the online survey, the chapter concludes with an overview of the limitations associated with the chosen methodology.

4.1 Expert Interviews

Prior to the online survey, semi-structured expert interviews were conducted. In the context of this research, this method served two functions. First, the expert interviews were used to gather fundamental insights into each of the research questions. In particular, the method was applied to gather data about the contribution of households at risk of energy poverty to demand-side flexibility in accordance with the first sub-research question. As further elaborated in the ensuing subchapter, the survey was originally intended as the main source of data to tackle this research question. Due to the lack of survey responses from members of households at risk of energy poverty, the research design was adjusted accordingly, primarily using the expert interviews to address this question instead.

Moreover, the qualitative method was directly targeted at the identification of injustices associated with the inability of households at risk of energy poverty to access technologies for demand-side flexibility, thereby addressing the main research question. Even though the interviews touched upon the second sub-research question as well, the survey that was carried out after the expert interviews was intended as the primary source of information thereof.

This alludes to the second purpose of the expert interviews. The information which was collected through them was directly incorporated into the survey design. In this way, the qualitative part of the methodology, the interview, was used in an exploratory way, to derive fundamental information about the topic, an approach suitable for the rather underexplored research background (Lawrence Neuman, 2014). The data from the interviews was then used to design the questions for the quantitative part of the research, the survey. In mixed-methods research, this approach is called instrument-building model (Creswell, 1999) and is used to adequately incorporate the appropriate information in the survey.

4.1.1 Selection of Interviewees

As previously alluded to, the interviews were conducted with people who are considered experts in the scope of this research. According to KAISER (2014), an expert possesses knowledge of a particular subject and is identified by the virtue of its specific knowledge, its position in a community, or its status. By applying this definition, a person was considered an expert if they possessed at least one of the following qualifications which enabled them to share insights into the research topic from either a social or a technical perspective, oftentimes even both.

The first of these qualifications encompassed the expert's profound knowledge about technologies for demand-side flexibility, obtained either through a background in research or the industry. Similarly, a person that possessed in-depth knowledge at the intersection of energy justice and digital technologies was considered an expert. Since, as mentioned previously, the German discourse around this topic is rather nascent both in academia as well as in policymaking, experts were also explicitly considered from outside of Germany. Due to the Anglo-Saxon origins of the scholarly concept of energy poverty, this particularly applied to researchers from the United Kingdom.

With a particular focus on the German case, the last qualification involved thorough knowledge about the life circumstances, including the energy consumption patterns, of those in the nexus of this research, that is, households at risk of energy poverty. Here, representatives from German consumer advice centers (*Verbraucherzentralen*) were considered as particularly suitable since their services also include energy consultations all around Germany which are free of charge (Verbraucherzentrale Energieberatung, 2024). It was assumed that households at risk of energy poverty regularly take advantage of the free consultations through which the experts have obtained substantial insights into their demographics as well as their energy consumption patterns which is relevant for both the abovementioned research questions as well as the survey design. Based on those qualifications, experts were identified. This process involved a thorough internet search according to the three previously outlined qualifications as well as a referral system based on already existing contacts. The initial contact was established via email where the research background was outlined, and experts were encouraged to participate in the interviews.

4.1.2 Interview Preparation

Under consideration of the two purposes of the interviews, their format as well as an interview guideline was determined. To warrant that the interviews loosely followed the same structure while also ensuring that each interviewee was able to incorporate their specific professional focus, a semi-structured approach was chosen. The open-ended questions of semi-structured interviews granted the flexibility to touch upon subjects which arose spontaneously during the conversation (Harvey-Jordan & Long, 2001). Simultaneously, an interview duration of one hour was determined to grant sufficient time to ask the intended questions.

Furthermore, an interview guideline after the framework for semi-structured interviews recommended by KALLIO ET AL. (2016) was created whose questions were formulated according to the research questions the method was intended to answer. The previous academic literature on which this research builds outlined in Chapter 2 as well as the theoretical framework and the case-specific insights further delineated in Chapter 5 were considered in the creation of the interview guideline. Given the exploratory character of the interviews, the guideline was regularly refined during the interview process, yet no significant adjustments were needed.

Accordingly, the interview guideline consisted of an introductory as well as a concluding part which remained similar throughout the interviews, and four main segments. After the introduction, questions dedicated to the contribution of households at risk of energy poverty to demand-side flexibility constituted the first main segment. This was followed by a section dedicated to the second sub-research question and thus the identification of spill-over effects. The last two segments were targeted at the identification of injustices associated with the current access of households at risk of energy poverty to technologies for demand-side flexibility as well as solutions to address these injustices. After concluding each of these four segments, the interviews were finalized.

Depending on the respective participant and their professional background, the guideline was slightly adjusted, and questions were either added or omitted, while the fundamental structure remained the same. In line with KALLIO ET AL.'S (2016) framework, a pilot test of the interview guide was conducted to assess the questions' comprehensibility and the overall duration. This test was executed both in an internal evaluation as well as through a field-testing with a potential study participant. The finalized interview guideline is accessible under Appendix A. Upon request, the guideline was shared with the participants prior to the interview. Once the invited experts agreed to participate in the research, the interviews were scheduled according to their availability.

4.1.3 Conduct of the Interviews

Each of the interviews was conducted digitally through a video conference meeting in Microsoft Teams. Following the interview guideline, they started with a brief introduction where the interviewer provided insights into the research background and obtained the expert's consent to record and transcribe the material for scientific purposes. The experts were then asked to briefly introduce themselves. Successively, the interviews touched upon questions about demand-side flexibility in the context of households at risk of energy poverty and their access to technologies for demand-side flexibility to derive insights about the first sub-research question. Furthermore, the participants were invited to give an assessment about potential spillover effects associated with households' access to technologies for demand-side flexibility on their energy consumption behavior.

Whenever fundamental injustices associated with the access of households at risk of energy poverty to technologies for demand-side flexibility arose during the interview, the experts were requested to elaborate further. Thereby, the main research question was directly addressed. Furthermore, the interviews were targeted at the identification of potential solutions to address the identified injustices, predominantly through suitable schemes initiated by the government. Depending on the interviewee's professional background as well as the natural flow of the conversation, varied emphasis was placed on each of the four main segments of the interview guideline.

Before concluding the interviews, the participants were granted sufficient time to comment anything they wanted to add to the discussion or ask further questions. This proved to be beneficial as many experts used this proposal to elaborate on a topic they were particularly interested in or to recommended further avenues of research. Afterwards, the interviewees were also invited to recommend further experts who could be interviewed as well, thereby applying a snowball sampling (Noy, 2008).

This way, a total of 12 interviews were conducted between the 29th of February and the 9th of April 2024. Out of them, eight were held in German and four in English. As planned, the interviews mostly remained within the predetermined time frame, except for the third and sixth interview which were intended to finish shorter due to the experts' availability. Table 4.1 provides an anonymized overview of the interviews, including the experts' professional background and the spoken language, the dates on which they were conducted, as well as the duration of the interview in minutes. As evident through this outline, each of the previously listed qualifications the experts were envisioned to possess were met. This ensured a balance between perspectives from theory and practice as well as academia, public and private sector, enabling a thorough and holistic understanding of the research topic and the triangulation of the obtained findings.

Table 4.1: Overview of Interview Participants

ID	Professional Background	Date	Duration (minutes)	Language
I01	Researcher from a German organization for applied research specializing on technologies for demand-side flexibility from a systems perspective	29/02/2024	57	German
I02	Employee from a German energy service provider focused on regionalization and time series with relevant publications around demand-side flexibility on a household level	01/03/2024	61	German
I03	Senior research fellow from a British university studying the social aspects of demand-side flexibility from a household perspective	05/03/2024	40	English
I04	Researcher from a British not-for profit research and policy advice organization working at the nexus of the energy transition, demand-side policies, and energy poverty	06/03/2024	60	English
I05	Researcher at a German research center managing and researching on cross-disciplinary projects around flexibility in the energy system	06/03/2024	61	German
I06	German manager in an international technology company responsible for corporate research in the field of sustainable energy and infrastructure; professor of multi-modal energy systems	08/03/2024	32	German
I07	Senior lecturer at a British university at the intersection of energy justice, ethical consumption, and innovation	08/03/2024	60	English
I08	Co-director of a German energy research institution with a background in municipal energy efficiency, climate policies, and education for sustainable development and energy poverty	14/03/2024	58	German
I09	Coordinator of a consumer advice center’s energy project on a German state level	14/03/2024	61	German
I10	British emeritus professor with a background in environmental justice, energy justice, demand-side flexibility, and energy poverty	20/03/2024	64	English

ID	Professional Background	Date	Duration (minutes)	Language
I11	Coordinator of a consumer advice center's energy consulting project for households at risk of energy poverty on a German state level	09/04/2024	62	German
I12	Regional instructor and trainer of a German Catholic welfare association's energy consulting project for households at risk of energy poverty called "*Stromspar-Check*"	09/04/2024	61	German

4.1.4 Thematic Analysis of Interviews

After the interviews were conducted, the recordings were transcribed. The automatic transcript feature of Microsoft Teams served as the first step towards the finalized transcriptions. The transcripts were downloaded and imported into MAXQDA, a software for qualitative data analysis. This tool was chosen as it provided a means to transcribe, code, and analyze the collected data. Since the automatic transcripts generated through Microsoft Teams exhibited copious errors, they were manually corrected while listening to the recordings a second time while simultaneously adding timestamps. This process facilitated the revisiting of interview segments during the coding process. The interviews were transcribed following a denaturalized approach as the meanings and interpretations of the spoken words rather than the underlying vocalization was of significance for the analysis (Oliver et al., 2005).

Interviews which were held in German were translated into English using the functionalities of the software tool DeepL. It is emphasized that these translations were not utilized to conduct the thematic analysis; for that, the original data sets were used to ensure that the experts' statements were interpreted correctly, and nothing was lost in translation. Instead, the translations were enclosed to grant those not fluent in German insights into the interviews, thereby ensuring accessibility. The transcriptions of the interviews are available in the Appendix. Marked as translations, the German transcripts are accessible under Appendix C. The English transcripts, in their original form, are presented under Appendix D.

Based on the transcripts, a thematic analysis was conducted. It was chosen as a research tool due to its flexibility and its potential to "provide a rich and detailed, yet complex, account of data" (Braun & Clarke, 2006, p. 78). Furthermore, BRAUN & CLARKE (2006), whose approach towards thematic analysis was applied in this research, claim that it is a suitable method to summarize features from a large data set and to generate analyses to inform policies. Thematic analysis is equally deployed to identify, analyze, and write about patterns, so-called themes, derived from the data.

Following the phases for thematic analysis as presented by BRAUN & CLARKE (2006), an initial set of codes was generated after the transcription of the interviews. A latent – interpretative – analysis was chosen as it was assumed that the experts conveyed their information in a straightforward manner, rendering the latent analysis of the interviewees' underlying opinions obsolete. Furthermore, a theoretical thematic analysis was chosen as the coding was dedicated to acquiring insights into particular research questions, thereby building on the previously outlined theoretical framework. Hence, the initial coding was conducted in line with the three research questions as well as along the energy justice framework to provide an initial "coding skeleton" in a deductive manner.

After finishing this step, the identified codes were clustered into potentially suitable themes. Initial ideas for the connections among codes and themes were derived. In the following phase, these ideas were reviewed; the consistency among the codes and themes as well as the validity of the coded data in relation to the entire data set was evaluated. This process resulted in the obliteration of two codes which were deemed as unfit for the analysis and ensured the inclusion of data which has previously been overlooked. The re-evaluation of the data set stopped as soon as it became evident that no major refinements were required anymore.

In the next phase, the themes and sub-themes were each given a suitable definition and name with regard to the research questions. The finalized guideline for thematic analysis, thus, consisted of the five themes named Flexibility Measures, Spillover Effects, Justice Framework, Technologies, and Schemes. The former two themes consisted of two sub-themes, both of which were identified deductively based on the existing literature, whereas the Justice Framework was further refined into ten sub-themes, seven were deductively taken from the existing energy justice framework, three resulted inductively from the data. The Technology as well as the Schemes theme comprised of six sub-themes each, identified in an inductive manner. The complete guideline for thematic analysis including the definitions as well as examples from the data set is accessible under Appendix B. This way, a thematic analysis was performed for the entire data set in an inductive/deductive hybrid approach which was further refined throughout the quantitative part of the research. Similar to the transcription process, the thematic analysis was executed with MAXQDA. This process provided the foundation for the finalized results of this paper.

Furthermore, the coding reliability was validated through the calculation of the inter-rater reliability score. Therefore, a sample of the interview data was presented to a second independent coder (Clarke & Braun, 2017). This method has been applied to ensure qualitative rigor and thus establish consistency of the research method (E. Thomas & Magilvy, 2011). Furthermore, as KOLBE & BURNETT (1991) acknowledge, intercoder reliability serves as "the standard measure of research quality" (p. 248), whereas the disagreement among researchers alludes to an inadequate operationalization of definitions and categories. Following the recommendations from the scientific literature, only a sample of the interviews was valuated through inter-rater reliability due to the large amount of data collected (Campbell et al., 2013; Hallgren, 2012). The sample comprised of twenty-minute segments from three randomly chosen interviews. After granting the coder sufficient time to get acquainted to the finalized coding guideline, he coded the sample, as well. Using the Intercoder Agreement feature of MAXQDA, the resulting code sets were compared.

The type of intercoder agreement was set to an overlapping rate of at least 75 % at the segment level to grant sufficient room for interpretation and variances among the coding approaches of the two researchers. Based on this, the inter-rater reliability score was interpreted using Cohen's Kappa (κ) where a κ between 61 and 80 % indicates a substantial and a κ above 81 % indicates an almost perfect agreement (Landis & Koch, 1977). The intercoder agreement bore a result of 80.52 %. It was thus concluded that the research method exhibited sufficient scientific rigor. In other words, the intercoder-reliability score indicates a high level of consistency among the coders and thus a high, almost perfect level of reliability.

4.2 Online Survey

Complementary to the expert interviews, a close-ended online survey was conducted. Initially, the online survey was intended to serve two purposes, the first of which was to gain insights into the contribution of households at risk of energy poverty to demand-side flexibility. As delineated subsequently, this goal was not sufficiently achieved since responses from members of households at risk of energy poverty remained scarce. Furthermore, the survey was intended to identify spillover effects associated with the access of households to technologies for demand-side flexibility on their energy consumption. In other words, the survey was dedicated as the main source of data for the first two sub-research questions. Correspondingly, the survey addressed two different target groups, namely households at risk of energy poverty, and households who had already adopted at least one technology for demand-side flexibility.

Against this background, there are several reasons for the choice of an online survey. First, it became evident through the interviewed experts that reaching members of households at risk of energy poverty would be challenging, particularly for a time-consuming interview. Hence, an approach which facilitated its spread over electronic and physical means while simultaneously decreasing the time expenditure for participants was required. Moreover, an anonymous survey was determined to be an appropriate choice because energy poverty and poverty in general may be linked to certain bias. Lastly, the two target groups necessitated a survey design which allowed a slightly different set of questions. Since online surveys enable a quick turnaround time and the reach of a large number of respondents, ensure confidentiality, and yield the option to include customized items (Jamsen & Corley, 2007), the method was chosen.

4.2.1 Survey Design

The conduct of the expert interviews and the initial gathering of insights into recurring themes marked the beginning of the survey design. This way, it was ensured that no information from the experts which could be used to further specify the survey questions were overlooked. This also enabled a close-ended, quantitative survey design since the answer categories were already identified through the expert interviews. The insights obtained from them enabled the use of such a standardized method suitable to address participants' attitudes and behavior (Bowling & Ebrahim, 2005), as is the case in this research.

Before specifying the survey questionnaire, a few fundamental decisions about its design were taken. Throughout the survey, participants were granted the possibility to elaborate through a "Further, please specify" option, thus decreasing potential response bias (Reja et al., 2003). Each question was non-compulsory and included a "Not specified" option. The answer options to questions which potentially suggested a socially preferred reply, for instance the gradation from social housing to home ownership, were randomized. Furthermore, no personalized data was collected through the survey as it was not deemed necessary for the research. Given the research background with the case study on the *Energiewende*, the survey was only available in German.

Under consideration of these fundamental decisions, the survey was implemented. Therefore, the software solution by Tivian was chosen due to its user-friendly interface and its conformity with German data privacy standards. The first page of the survey briefly informed the participants about its scope, content, and contact data of the researcher. It notified them about the anonymous treatment of their data and provided a consent form as well as a data protection notice. After giving their consent, respondents were asked to grant demographic information relevant in the scope of this research such as the number of household members and minors, and their current housing situation, for instance whether they live in a rented or owned home, thereby ensuring a logical and straightforward entry point into the survey. This was succeeded by a question about the household's possession of one or more of the following energy technologies. Here, the technologies for demand-side flexibility identified by the interviewed experts were outlined, namely solar panel on the roof, balcony solar module, smart meter with communication unit, smart plug, smart thermostat for remote-controlled adjustment of the heating, controllable lamps and lights, heat pump, app or dashboard for automatic adjustment of the energy consumption, battery storage, and wall charging station for charging electric cars. The ensuing question also targeted an additional digital technology for demand-side flexibility, namely apps or websites which grant information about the current situation of the energy system. Here, participants were asked to indicate the frequency of their use of such on a matrix scale from 1 to 5, where the former indicating that respondents never used such technologies, whereas the latter implied the daily use.

If participants stated that they used at least one such technology and/or use the previously mentioned apps or websites not never, they were asked to answer three additional question blocks. The first thereof consisted of eleven statements. On a matrix scale ranging from 1 to 5, the participants were asked to indicate the degree to which they agreed with them. These statements directly reflected on the second sub-research question aimed at identifying spillover effects on their energy consumption associated with the adoption of technologies for demand-side flexibility. Furthermore, they mirrored the statements of the experts regarding the spillover effects mentioned throughout the interviews. Correspondingly, the statements homogeneously opened with the line "Since I am using the previously chosen technology/technologies in my household…". Afterwards, participants were asked to indicate the extent to which these technologies changed their energy consumption, their level of agency about it, their willingness to introduce further technologies into their household, and their opinion towards a technology automating their energy consumption.

The second and third block directly dedicated to participants already owning technologies for demand-side flexibility subsequently inquired who is responsible for the acquisition of said technologies and who, on the other hand, uses them. Back on the path for both target groups, a multiple selection question invited participants to choose what activities they actively undertake to save energy or to relieve the load on the grid. Here, socially-derived flexibility measures which were stated by the experts were presented. This question was hence dedicated to identifying the contribution of households at risk of energy poverty to demand-side flexibility while enabling a comparison to more affluent households. Subsequently, participants were asked to state the degree to which they agreed with eight statements on a matrix scale. Six of them were dedicated to assessing their overall energy consumption behavior. The remaining two served as a measure to gain insights into the degree to which participants were at risk of energy poverty. Therefore, they were asked to assess the financial difficulties of paying their energy bills as well as of sustaining themselves on their current income.

The survey concluded with more specific demographic questions such as participants' age group, their gender, their current occupation, and the German state they are from. Lastly, a question was designed to inquire about households' monthly net income. Participants were granted a precise definition which streams of income are included under this term. Subsequently, they were able to choose between gradually increasing income clusters. These reflected on the German unemployment benefit for a single person, and from that gradually increased in divisions of 1,400 €. This rather uncommon approach was chosen since, according to the most recent German statistics from 2023, a single person lives at risk of poverty if their net income lies below 15,715 € annually (Statistisches Bundesamt, 2024). This accounts for an income of around 1,312 € per month. Divided by the respective number of household members, this question was designed to reflect a central metric of energy poverty, that is, income. The threshold was rounded up from the previously calculated monthly income to ensure uniformity; furthermore, any results obtained from this question served as one, rather than the only, determinant contributing to energy poverty. The final page of the survey stated that the respondent's participation was successful and thanked the contributors. A translated version of the online survey is accessible under Appendix E.

4.2.2 Dissemination and Analysis of the Survey

After finalizing the survey design and ensuring that the paths and answer options followed the previously presented logic, the dissemination phase started. The survey was activated on 11th of April 2024 and ran for a period of approximately four weeks, until the 15th of May. To distribute the survey among a broad sample while ensuring that the two target groups were addressed, several approaches were chosen. Attempting to reach participants from households at risk of energy poverty, German social welfare and employment offices were first contacted over the telephone to inquire whether a QR code with a brief invitation and a link to the survey could be displayed in waiting rooms or on notice boards. After obtaining their consent as well as the e-mail addresses of several such offices, a document with said QR code was sent out directly to them. German non-profit associations who are potentially also in contact with people at risk of energy poverty were contacted in a similar manner.

Furthermore, an invitation with a link to the survey was posted in Facebook groups where members shared their budgeting recommendations and experiences. Apart from Facebook, households at risk of energy poverty were targeted through the social media platform Instagram. Here, German accounts with a focus on cost saving and budgeting were directly contacted, inquiring whether they were interested to share an invitation to the survey in their temporary story. Likewise, accounts led by non-profit associations and groups advocating for topics around social justice and inclusion were contacted. Participants from households who already possessed technologies for demand-side flexibility, on the other hand, were predominantly contacted through Facebook. Therefore, a brief explanation of the survey's scope and purpose followed by the corresponding link was posted into several groups whose topics suggested that the target group was represented. Such groups included ones dedicated to smart home automation, photovoltaics, heat storage, and heat pumps.

This strategy permitted the collection of 133 full survey responses and an overall completion rate of 22.58 %. With the end of the dissemination period, the survey was closed. The collected data was downloaded from Tivian. After cleaning the data in Microsoft Excel, it became evident that, despite the researcher's best efforts and the deployment of various channels to reach members from households at risk of energy poverty, rarely anyone from this target group participated in the survey. It was, however, possible to obtain a plethora of responses from the second target group. This led to the decision to treat the survey as the main source of data for the second sub-research question, supported by the information from the expert interviews. However, given the lack of insights about the contribution of households at risk of energy poverty to demand-side flexibility from the survey, the first sub-research question was predominantly answered through the expert interviews.

Against this background, the data was statistically analyzed with the software tools Microsoft Excel and IBM SPSS Statistics under consideration of the second sub-research question which was intended to be predominantly addressed through the survey. The analyzed data was used to triangulate the findings from the interviews. Furthermore, following the inductive/deductive hybrid approach, the survey analysis yielded an additional injustice which was derived in an inductive manner and incorporated into the research findings.

4.3 Limitations of the Methodology

The chosen methodology is associated with central limitations. Given the research background, a significant shortcoming of the methodology was that members from households at risk of energy poverty were not interviewed themselves. In accordance with the definition by KAISER (2014), interviewees from households at risk of energy poverty were considered experts, possessing in-depth knowledge about the studied subject due to their position in a community. Thus, direct insights from households at risk of energy poverty would have considerably contributed to the results. Although it was intended to mitigate this limitation in the quantitative stage of the research, this target group could not be adequately reached through the survey either.

A further limitation of interviews is associated with their reliability, the extent to which a research instrument yields the same results on repeated trials (Alshenqeeti, 2014). The previously introduced inter-rater reliability score of 80.52 % served as an instrument to determine that a repeated trial through a second independent coder granted a substantial agreement. However, qualitative data analysis still remains, to a certain extent, interpretative (Clarke & Braun, 2013) which critically questions the extent to which the results of the inter-reliability score should be emphasized. Nonetheless, the practice of inter-rating served as an opportunity to critically approach and discuss the interviews' content and scope at an early stage which significantly benefitted the quality and depth of the analysis.

An additional noteworthy aspect is the researcher's German nationality. Studying the topic based on one's own country context ensured a profound understanding of the case from a historical, cultural, as well as administrative perspective. Furthermore, the researcher's proficiency in German facilitated the contacting and interviewing of experts. This potentially enhanced the research's internal validity, that is, the extent to which the findings make sense (Miles & Huberman, 1994). Nonetheless, the risk of unconscious bias reflected in the results due to the researcher's nationality should be considered. However, the conduct of interviews from different professional backgrounds as well as the mixed-methods approach enabled the triangulation of results which, according to authors such as GLINER (1994), significantly contribute to internal validity.

This paves the way for the acknowledgement of another limitation regarding the survey design, namely its mere availability in German. While the focus on the case of the *Energiewende* justifies this choice, it is undeniable that not everybody living in Germany who potentially possesses technologies for demand-side flexibility and/or lives at risk of energy poverty is proficient in the language. Hence, the option to choose between languages might have resulted in additional survey participants. This aspect is directly related to the last limitation acknowledged here. Due to the relatively small number of participants, the survey is not statistically significant but instead rather mirrored tendencies observed in the data set. It is against these limitations that the results in Chapter 6 were interpreted.

5 The German *Energiewende*

The following chapter grants further insights into the German energy transition. This practice-oriented and case-specific expansion of the literature review serves two purposes. The underlying research enabled the identification of central characteristics of the German case. This ensured that the applied methodology and the results closely mirrored the practical as well as scholarly developments around the *Energiewende.* Moreover, the chapter functions as a prelude to the results, providing additional information through which the subsequently presented research findings are contextualized. Therefore, the chapter first introduces central sociopolitical aspects of the German *Energiewende* which characterize it as a noteworthy case on which to assess the intersection of energy justice, energy poverty, and demand-side flexibility. The chapter then proceeds with an outline of the legal and administrative framework of the *Energiewende* before addressing the topic of energy poverty from a German perspective.

5.1 The Sociopolitical Background of the German *Energiewende*

Approaching the topic of energy justice from the perspective of households at risk of energy poverty is particularly relevant in the German case due to three intertwined sociopolitical aspects characteristic for the country's energy transition. The first of them is closely related to the overall energy transition publicly referred to as *Energiewende*. With the aim of establishing a more sustainable and low-carbon energy system, the *Energiewende* is an ambitious project with manifold social, societal, and economic implications. Officially launched as a pioneering initiative by the federal government in 2000 with the Renewable Energy Sources Act (*Erneuerbare-Energien-Gesetz,* EEG), the *Energiewende* included the shutdown of existing nuclear and coal power plants, the expansion of renewable energy sources with an emphasis on wind farms, photovoltaic, and gas power plants as well as the corresponding energy grid development (Radtke & Kersting, 2018).

Since then, the gradually increasing share of renewables, amounting to nearly 52 % of the country's electricity consumption in the year 2023, emphasizes the country's progress towards achieving their climate goals (Presse- und Informationsamt der Bundesregierung, 2024b). Therefore, it is considered that Germany has one of the most enabling environments for the energy transition which illustrates the *Energiewende*'s success on the federal level (World Economic Forum, 2023). Yet, the second aspect of the country's energy transition stands in contrast with the previously outlined regulatory and political accomplishments. On a citizen level, skepticism and resistance against local energy initiatives do persist, underscoring the divergence between the social acceptance of the *Energiewende* on a global and local level (Bosch & Schmidt, 2020; Höfer et al., 2016; Mai, 2018). As DÜTSCHKE ET AL. (2019) emphasize, the success of the German energy transition is not only dependent on technological progress, but also on favorable social, political, and economic conditions. These are, in turn, closely related to the social acceptance which thus represents a central cornerstone of the *Energiewende*.

This leads to the third noteworthy aspect of the German energy transition, the energy prices for consumers. In a European comparison, the country demonstrates the highest electricity prices for households, particularly for smaller energy consumers (Eurostat, 2024). Over the last twenty years, a gradual increase of electricity prices for households was recorded (Verivox, 2023). Considering that there is a dichotomy in terms of the successful progress of the *Energiewende* on a federal level and the social acceptance on a citizen level which is, however, imperative for the expansion of renewable energy sources, it becomes evident that these aspects are highly intertwined. Even more so, the comparatively high energy prices for consumers potentially affect the social acceptance and reflect on the federal *Energiewende* strategies, particularly for less affluent households. These three intertwined sociopolitical aspects lay the foundation to adequately situate the topic of energy justice and energy poverty in the German context. For further context, the central legal and administrative decisions that shaped the *Energiewende* while establishing a connection to the research topic are outlined.

5.2 Legal and Administrative Framework of the German *Energiewende*

At the core of the *Energiewende* lies Germany's commitment to switch over to a non-nuclear, renewable energy system. Therefore, the country issued its first federal law promoting the use of renewable energy sources in the beginning of the 1990s. Yet, prior to that, some states had already supported the expansion of renewables through their own funding programs. Due to the country's federal structure, the states are permitted to define their own energy policy goals within the framework of federal energy laws and control their implementation. Federal authorities and institutions, on the other hand, play a predominantly coordinating role, for instance in terms of grid access, monopoly control, and research funding. The success of the energy transition, hence, not only depends on the federal decisions but largely on the actions of individual states as well as the coordination of regional authorities. This multi-layered governance structure in which both federal government and states pursue their own energy policy goals potentially results in the suboptimal distribution of energy infrastructure, possibly at the expense of supply security (Wurster & Köhler, 2016). This, in turn, yields distributional as well as procedural justice implications.

In 2000, the previously mentioned Renewable Energy Sources Act was introduced to further advance renewable energy in Germany. The Act legally bound grid operators to incorporate renewable electricity into the grid while simultaneously granting entities owning renewable energy plants surcharges above the market price, so-called feed-in tariffs (*EEG-Umlage*) (Bosch & Schmidt, 2020). Amidst the spread of renewable energy sources in the 2010s, the feed-in tariffs led to energy price surges for consumers. Several authors critically stated that the program put a financial burden predominantly on low-income households, further intensified by the fact that only those owning renewable energy assets profited from them (Diekmann et al., 2015; Lutz & Breitschopf, 2016). Feed-in tariffs, thus, are also associated with issues around distributional justice.

2023 marked the year when the Renewable Energy Sources Act was amended in accordance with the Paris Agreement and its 1.5-degree trajectory. The treaty of the Paris Agreement was signed by 196 parties and entered into force in 2016. It presents a joint action plan to limit global warming below 2 °C above pre-industrial levels and includes a reference to the 1.5 °C goal (Savaresi, 2016). Correspondingly, at the core of the amended German Act lie the goals of limiting global warming below 1.5 °C, reducing the dependency on fossil fuels, and generating at least 80 % of gross electricity from renewable energy sources by 2030. The previously considered feed-in tariffs were discontinued (Presse- und Informationsamt der Bundesregierung, 2023).

Together with the Renewable Energy Sources Act, the federal government initiated an agreement with the nuclear companies for a systematic exit from nuclear energy in 2000. Under a new government ten years later, a fundamental change was announced, presenting the highly controversial topic of nuclear energy as a significant cornerstone of the *Energiewende*. Yet, in light of the 2011 nuclear accident of Fukushima, the definite phase-out of nuclear energy was announced (Wurster & Köhler, 2016). Consistently, the last nuclear plants were shut down in 2023 (Präger et al., 2023). The identification of geological repositories for the associated waste, however, illustrates that the German discourse around nuclear energy is still ongoing and sparks further spatial as well as distributional justice considerations.

Due to the substantial increase of energy costs throughout the years 2022 and 2023, the German government provided financial support for the consumers. Publicly known as "energy price brakes" (*Energiepreisbremsen*), consumers were able to obtain 80 % of their annual consumption forecast at lower rates. Those who consumed less than the 80 % of the consumption forecast were granted the savings as an additional reward (Bundesnetzagentur, 2024). While the program was designed to decrease energy prices, it was not directly dedicated to those at risk of energy poverty. The energy justice implications of such schemes are discussed in Chapter 6.

Furthermore, several decisions around the *Energiewende* are equally pertinent in the scope of energy justice as well as demand-side flexibility. In accordance with a directive from the European Union, the German Bundestag passed the Act on the Digitalization of the Energy Transition (*Gesetz zum Neustart der Energiewende*) in 2016. The Act stipulated the rollout of smart meters for those whose annual energy consumption exceeds 6,000 kWh. Furthermore, upper price limits for the installation of smart meters as well as data protection and security standards for the smart grid infrastructure were defined. Due to financial as well as regulatory barriers, the Act progressed slowly; few smart meters were installed throughout the following five years. In 2021, under a new government and the competence of the Federal Ministry of Economics and Climate Protection, a new bill was drafted to restart the digitalization of the energy transition (Gegner, 2023).

The resulting Act to Restart the Digitalization of the Energy Transition stipulates the cost limit of a smart meter system for consumers at 20 € annually and the billing of already existing smart meters per quarter of an hour. Furthermore, it obliges electricity suppliers to introduce dynamic time-of-use tariffs based on the federal spot price of electricity from 2025 onwards (Gegner, 2023). Particularly the latter measure in the realm of the Act on the Digitalization of the Energy Transition elicits questions around energy injustices which are further discussed in the subsequent chapter, given that households are exposed to higher price fluctuations to cover their energy needs.

The rollout of smart meters as defined in the Act to Restart the Digitalization of the Energy Transition also plays a role in the context of demand-side flexibility. Smart meters represent an enabling technology towards the incorporation of technologies for demand-side flexibility on a household level. Said technologies are characterized by their ability to provide flexibility for the energy system by shifting the electric demand. In Germany, these technologies have not yet taken up on a larger scale (Gillich et al., 2024).

Congruently, Gleue et al. (2021) name the scarcity of smart meters as a reason for the low application of time-variant tariffs in Germany. The authors state that a 15 % shift of household consumption in Germany potentially resulted in direct emission savings of 0.8 %, particularly in the summer months. This highly depends on the country context and the associated social practices which directly influence demand-side flexibility. Stute et al. (2024) add to the discussion by elaborating that dynamic tariffs yield economic benefits for German households in possession of technologies for demand-side flexibilities while acknowledging that these technologies are associated with investments upfront.

A short outline of recent stipulations in the realm of renewable heating concludes this overview of the German *Energiewende*. With the launch of the Act for Renewable Heating (*Gebäudeenergiegesetz*) in the beginning of 2024, the German government aims to facilitate the transition towards climate-friendly heating systems. Until 2028, new heating systems are required to use at least 65 % of renewable energy. Furthermore, the government provides financial support for the replacement of existing heating systems (Presse- und Informationsamt der Bundesregierung, 2024a).

The Act for Renewable Heating advances in conjunction with the Heating Planning Act (*Wärmeplanungsgesetz*) which paves the way for the systematic introduction of a nationwide heat planning throughout Germany. With a focus on local conditions, the Act is intended to develop regional strategies targeted at the gradual transition of the heating supply to renewable energy sources. Typically carried out by municipalities, the so-called heating plans are to be finalized no later than mid-2028 (Bundesministerium für Wohnen, Stadtentwicklung und Bauwesen, 2023). A further factor which bears implications for the switch towards heating from renewable energy sources is Germany's transition of the heating and transport sector from a national to the EU Emissions Trading System (ETS II) from 2027 onwards. For these sectors, the price for a ton of CO_2 will then be determined by the demand for fossil fuels in the sector, potentially resulting in amplified fuel and heating costs for consumers (Görlach, 2023).

It becomes evident that the German *Energiewende* is an initiative concurrently shaped by the states, the private sector, the federal government, as well as supranational entities. Furthermore, the energy transition yields profound implications for private consumers and serves as a basis for the emergence of energy injustices. This is closely related to energy poverty, a central topic of this research which is thus outlined subsequently.

5.3 Energy Poverty in Germany

While energy poverty has a decade-long history in countries such as the United Kingdom, it has only recently caught wider public attention in Germany. Correspondingly, scientific contributions are rare but gaining momentum, starting to emerge in the 2010s. KOPATZ ET AL. (2010) acknowledge that, albeit not framed under the term energy poverty, several regional initiatives dedicated to alleviating energy poverty were launched in the years prior to their work. Instead of energy poverty, expressions such as energy security, poverty prevention through energy saving, and sustainable energy consumption in poverty households were used.

Here, the authors state that local initiatives, predominantly led by municipalities, were oftentimes implementing measures ahead of the federal government. This illustrates that the existing offers dedicated to the alleviation of energy poverty differ among regions and states. In this context, KOPATZ ET AL. (2010) introduce the "*Stromspar-Check*" (Electricity Savings Check) as the first federal initiative. As this project still exists and has been expanded since its launch in 2009, a representative from the *Stromspar-Check* has also been interviewed for this research.

Furthermore, KOPATZ ET AL. (2010) remark that both the technical infrastructure such as household appliances as well as bureaucratic barriers constitute to energy poverty. Several other factors which bear a high potential to save energy and thus costs, among them the insulation of the building, the presence of incentives for energy saving, as well as the presence of energy consultations in the proximity of the households, are mostly outside the individual sphere of those affected by energy poverty. In this regard, not only households dependent on social welfare or unemployment benefits are at risk of energy poverty, but also those in debt or in employment just above the poverty line (Kopatz et al., 2010). Here, it has to be remarked that the German unemployment benefit (*Bürgergeld*) grants a financial aid that includes a predefined proportion for energy costs which do not necessarily cover the actually occurring costs (Opielka & Strengmann-Kuhn, 2022). Yet, KOPATZ ET AL. (2010) also acknowledge that those in employment just above the poverty line are potentially even more affected by energy poverty than those receiving social transfers.

In 2012, the German government stated that neither a distinct definition nor direct policy interventions for energy poverty were required. Instead, energy poverty was treated as poverty; measures include the adjustment of social benefits in case of rising energy costs. Furthermore, the government recommended to decrease energy costs through energy efficiency measures (Deutscher Bundestag, 2012). TEWS (2013) challenges this perception. She perceives energy poverty as a structural problem of low-income households' limited ability to meet a necessary demand for energy services at disproportionately high costs or only insufficiently. Hereby, a low income and high energy prices determine energy poverty, yet a lack of energy efficiency in residential buildings and energy-inefficient appliances are presented as structural causes (p. 2).

In an intersectional approach, GROẞMANN (2017) outlines that there is a whole interplay that constitutes to energy poverty. In the context of Germany, she names social characteristics of households, namely income, age, household composition, gender, cultural background, and health, the areas in which discrimination applies such as the housing market, and policies relevant in the sphere of social inequality as relevant (p. 70). KAHLHEBER (2017) adds to the discourse that various disadvantages and vulnerabilities on an individual level, ranging from language or comprehension difficulties, illness, small children, lack of financial reserves, as well as the lack of budgeting and planning skills influence a households' risk of energy poverty. Changes of the previously outlined constellations in combination with the overall complexities and lacking transparency of energy procurement and energy consumption further complicate the households' situation, the author states. STRÜNCK (2017) contributes to the discourse that households with children, particularly single parents, are statistically at a high risk of energy poverty. The same applies for single households where women are at a slightly higher risk than men to live in energy poverty.

This illustrates that, despite it being a central factor, energy poverty is not only dependent on income but rather a highly multifaceted phenomenon, simultaneously influenced, among others, by household infrastructure, social practices, and the decisions of third parties on the local as well as the federal level. Against this background, Germany neither exhibits any policies directly targeted at the alleviation of nor an official definition for energy poverty. Instead, the government still addresses energy poverty in the general context of poverty (Bode, 2022). Hence, due to the absence of information regarding the number of people in energy poverty, statistics on poverty in Germany indicating that 17.7 million people – 21.2 % of the population – are affected (Statistisches Bundesamt, 2024) serve to understand that energy poverty is not a mere marginal phenomenon. The following chapter which presents the results of the case study of Germany directly draws on the previously introduced sociopolitical aspects as well as the decisions of the *Energiewende* and the scientific contributions of energy poverty in Germany.

6 Results

The following chapter presents the research findings obtained through the expert interviews and the corresponding survey. Structured along the research questions, the ways in which households at risk of energy poverty currently contribute to demand-side flexibility are outlined first before introducing the spillover effects associated with the access to technologies for demand-side flexibility on households' energy consumption behavior. Under incorporation of the two sub-research questions, the chapter ends with an overview of the injustices associated with the current access of households at risk of energy poverty to technologies for demand-side flexibility.

6.1 Households at Risk of Energy Poverty

The following subchapter directly addresses the first sub-research question, that is, the ways in which households at risk of energy poverty currently contribute to demand-side flexibility. Due to the lack of survey responses from members of households at risk of energy poverty, this question was primarily answered through the expert interviews. Nonetheless, a comprehensive answer to the research question was enabled through the interviews, particularly obtained through I08, I09, I11, and I12 who directly work with people at risk of energy poverty as well as from the remaining experts' thorough theoretical and practical understanding of the matter.

6.1.1 Household Characteristics Potentially Contributing to Energy Poverty

To fully comprehend the contribution of households at risk of energy poverty to demand-side flexibility, it is essential to demarcate central characteristics which contribute to said risk first. Such a differentiated approach has been chosen in line with the experts' statement that energy poverty is not determined through a single factor such as the level of income; rather, it is a highly complex and multifaceted phenomenon, sometimes even slightly ambiguous. I04 summarizes this by stating that to derive any kind of broad generalizations about people's ability to be flexible necessitates an understanding of their starting points which are predominantly related to their demographics rather than their income (personal communication, March 6, 2024).

One of these starting points, the experts homogeneously indicated, is the housing situation. Compared to those who own their home, households living in rental arrangements exhibit a greater tendency to be at risk of energy poverty. In case of the latter, landlords and landladies are primarily responsible for the thermal insulation and the heating system. The experts unanimously remarked that landlords and landladies tend to be hesitant to commence such retrofits. Since these aspects significantly contribute to households' energy bills, they influence their risk of energy poverty. Additionally, renters are frequently granted limited agency to undertake these adjustments themselves. While this certainly not always applies, the potential outcome are thermally inefficient homes equipped with outdated, energy-intensive heating infrastructure. Contrastingly, responsible entities in the more regulated social rental sector exhibit an increased tendency to invest in renovations and energy-efficient technologies compared to the private rental sector. Hence, albeit households in the social rental sector are still at risk of energy poverty, they are to a lesser extent.

A further aspect mentioned by the interviewed experts which greatly contributes to a household's risk of energy poverty is the household composition. Families with young children, for instance, are at a higher risk of energy poverty than households without children due to increased financial and time restraints. Judging from the experience of the consumer advice centers, the *Stromspar-Check*, and I08, single parents and particularly single mothers face an increased risk, as well. Deriving insights from their regular use of the free energy consultations from the *Verbraucherschutzzentralen* and the *Stromspar-Check* according to I09, I11, and I12, the same applies to single households.

Furthermore, the employment status and the number of jobs household members undertake is a significant aspect, the experts consistently stated. The extent to which household members work from home might be a risk factor as it increases the energy consumption of a household in the long term. Moreover, unemployment and retirement increase the risk of energy poverty as household members potentially spend a significant proportion of their day at home which reflects in their use of energy. This is related to an additional risk factor of energy poverty, namely age. Elderly people are at an increased risk of energy poverty, mirrored in their regular use of the consumer advice centers and the *Stromspar-Check*. Nevertheless, the experts acknowledged that the risk of energy poverty persists across ages. Less of a focus within the interviews but still mentioned by I11 and I12 was that immigrants might be increasingly exposed to the risk of energy poverty, referring to additional language and administrative barriers these households face.

A further topic the majority of interviewees touched upon were "complex problems" (I11, personal communication, 9 April, 2024), personal burdens or "strokes of fate" (I12, personal communication, 9 April, 2024) with which members of households at risk of energy poverty are frequently confronted. Here, I08, I09, I11, and I12 elaborated that these problems in combination with personal obligations significantly restrict the households' ability to dedicate resources to their energy consumption. In this nexus, the experts also mentioned that, albeit households at risk of energy poverty tend to be aware of central strategies to save energy and thus costs, a lack of knowledge thereof represents a further risk factor of energy poverty.

Against the background of these characteristics, the interviewees wholly agreed that households at risk of energy poverty are predominantly small energy consumers compared to more affluent households who tend to not only possess more technologies overall, but also more energy-intensive ones, such as electric vehicles. I05 encapsulates this by stating that, against a household with an electric vehicle that has a solar system with a battery storage, the consumption of households at risk of energy poverty accounts for "peanuts" because the former capacities are significantly greater (personal communication, 6 March, 2024).

Usually, households at risk of energy poverty do not own such technologies. Instead, household appliances such as fridges, washing machines, and potentially dishwashers and dryers frequently constitute the largest share of their energy consumption. Furthermore, the household appliances used by them tend to be comparatively old and energy inefficient. Correspondingly, these households are usually not in the possession of technologies for demand-side flexibility, particularly those from the private rental sector. This also corresponds with the limited flexibility capital POWELLS & FELL (2019) attribute to households at risk of energy poverty.

A central factor hitherto largely unconsidered is the household income. While it is a central determinant of energy poverty, the previously outlined aspects illustrate that it is not the only one. Nonetheless, the experts homogeneously stated that low-income households and those receiving social benefits such as unemployment benefit, basic income support, and housing benefit, as well as top-up workers (*Aufstocker*) tend to be at risk of energy poverty. The previous enumeration grants fundamental insights into demographic characteristics households at risk of energy poverty might exhibit. It should be acknowledged, however, that it does not paint a full picture of the multifaceted topic of energy poverty and instead invites future researchers to investigate the German case more closely. Moreover, whilst these factors do determine the risk of energy poverty, it is not indicated that, for instance, every household in the private rental sector is at risk of energy poverty. Oftentimes, it is rather a combination of such factors which puts households at increased risk, illustrating the complex, slightly ambiguous endeavor of delineating definite household characteristics constituting to this.

6.1.2 The Contribution of Households at Risk of Energy Poverty to Demand-Side Flexibility

The identification of central household characteristics which contribute to the risk of energy poverty enable a holistic answer to the first sub-research question. A fundamental factor which significantly affects the contribution to demand-side flexibility are the rather poorly insulated buildings and the energy-inefficient heating infrastructure of the buildings in which households at risk of energy poverty tend to live. These potentially limit their ability to contribute to demand-side flexibility. The limited control over the installation of technologies for demand-side flexibility, particularly in the private rental sector, augments this. A further factor which significantly constrains households' access to technologies for demand-side flexibility is income. Less affluent households lack the financial means associated with the substantial investment costs.

Moreover, their contribution to demand-side flexibility is decreased due to factors such as children, single parenting, and employment, not seldom multiple ones, which significantly narrow households' ability to shift energy consumption in time. This is further intensified through their limited ability to gain insights into and control over their energy patterns, factors closely related to the rental sector as well as limited access to technologies for demand-side flexibility. This factor potentially even inhibits such households at risk of energy poverty whose members tend to have a comparatively greater ability to shift their energy consumption, for instance due to retirement and unemployment, to appropriately contribute to demand-side flexibility.

Furthermore, while it was illustrated that characteristics of households at risk of energy poverty might negatively influence their ability to contribute to demand-side flexibility, the same applies the other way around, as the experts unanimously stated. In other words, the risk of energy poverty might further exacerbate due to households' limited ability to contribute to demand-side flexibility. This interplay between household characteristics constituting to energy poverty and their resulting ability to contribute to demand-side flexibility is illustrated in the following figure. Amidst the possibility of rising energy prices and the introduction of dynamic time-of-use tariffs as outlined in in Chapter 5, this trajectory might gradually deepen in the future, representing a source of injustices.

Decreases ability to contribute to demand-side flexibility

Household Characteristics Contributing to the Risk of Energy Poverty	Resulting Ability to Contribute to Demand-Side Flexibility
• Private rental • Social rental	• Limited control and agency about thermal insulation, heating system, and installation of technologies for demand-side flexibility • Limited insights into their energy patterns
• Children • Single parenting • (Multiple) employment • Lack of knowledge about energy saving measures • Complex personal problems, burdens, strokes of fate	• Restricted ability to shift energy consumption in time • Limited insights into their energy patterns

• Financial inability to invest in energy-efficient technologies and ones for demand-side flexibility
    • Low-income households
    • Recipients of social benefits	

• Unemployment • Retirement • Thermally inefficient housing stock • Use of outdated heating systems	Increases household energy consumption and thus load on the grid

Further exacerbates risk of energy poverty

Figure 6.1: The Interplay between Characteristics of Households at Risk of Energy Poverty and their Resulting Ability to Contribute to Demand-Side Flexibility

Despite their limited ability to contribute to demand-side flexibility, a significant proportion of households at risk of energy poverty contributes to demand-side flexibility, nonetheless. Due to their limited access to technologies for demand-side flexibility, the interviewees unanimously stated that households at risk of energy poverty predominantly tend to resort to manual actions over which they have direct control in a rental situation. According to I09, I11, and I12, these measures include a decrease in the use of warm water, particularly through a reduction of shower times, an adjustment of their cooking behavior, a scaling down of the heating system – as I04 and I08 raised awareness for, even to a potentially unhealthy extent –, switching off devices in standby, as well as the decision to use household appliances such as dryers as scarcely as possible. Although these measures do decrease the burden on the grid to a small extent, they predominantly contribute to an overall saving of energy.

Apart from these actions, households at risk of energy poverty undertake measures to increase the thermal efficiency of their homes through the sealing of windows and doors.

Propelled by the dissemination from German consumer advice centers and the *Stromspar-Check,* they tend to use switchable power strips. Through occasional subsidies, a small minority of households at risk of energy poverty is gaining increasing access to photovoltaic systems for their balcony. This, however, largely depends on the availability of the respective state's or municipal's funding programs and is still associated with comparatively high costs for the households, I11 and I12 explain (personal communication, 9 April, 2024). In this context, consumer advice centers and the *Stromspar-Check* play a significant role as they provide guidance and the required equipment. With the transition from flat to dynamic time-of-use tariffs in the future, the interviewees expect these households to increasingly shift their domestic loads manually in time in expectation of small financial remunerations.

Against this background, the first sub-research question was answered as follows: The ability of households to contribute to demand-side flexibility is limited which potentially increases their risk of energy poverty even further. This is primarily due to factors outside of the households' scope and control, among them their limited access to technologies for demand-side flexibility. However, a substantial proportion of these households contributes through socially-derived flexibility measures which illustrates their general willingness to participate in the energy transition. Furthermore, in pre-emption of the main research question, the following fundamental injustice was identified through the results of the first sub-research question: *Due to factors largely outside of the control of households at risk of energy poverty, among them their limited access to technologies for demand-side flexibility, their contribution to demand-side flexibility is limited which potentially increases their risk of energy poverty even further.*

6.2 Households with Access to Technologies for Demand-Side Flexibility

The ensuing subchapter addresses the second sub-research question which tackles the spillover effects associated with the access of households to technologies for demand-side flexibility on their energy consumption behavior. This question was primarily answered through the online survey and triangulated with the findings from the expert interviews. Before addressing the spillover effects from technologies for demand-side flexibility, central demographics of the surveyed participants are outlined to put the subsequent research findings into perspective.

6.2.1 Characteristics of Households with Access to Technologies for Demand-Side Flexibility

In line with the research question, the survey directly addressed households who already possessed at least one technology for demand-side flexibility. Since merely eight of the

133 participants did not own any such technology, this goal was met. Before directly addressing the spillover effects, some fundamental insights about the participants' demographics that were discovered through the statistical analysis are provided to obtain a thorough understanding of their characteristics. Correspondingly, 87 % of the surveyed participants were male. They were predominantly middle-aged, averaging between 45 and 54 years; no minors took part in the survey. 85 % of the respondents indicated they were employed, the majority of which full time, 9 % were retired. With one and four participants, respectively, non-employed and students were the minority.

People from every German state except of Thuringia contributed, with most participants living in North Rhine-Westphalia, Bavaria, and Baden-Württemberg. Determined on the basis of the Gross Domestic Product (GDP) per head, these three states belong to the most affluent ones (Statistische Ämter des Bundes und der Länder, 2024). Two-people households were the most common constellations, closely followed by three and four household members, together contributing to 46 % of the chosen options. With 15 participants stating that they were living in single households, this constituted the fourth largest group. Slightly more than half of the participants indicated that there were no minors living in their household. In 28 of the contributing households lived one child, in 27 two, and in merely four lived three children.

With over 77 %, the majority of participants specified that they own their home, the remainder lives in rented homes; nobody indicated that they lived in social housing. Furthermore, the statistical analysis yielded that more than 80 % of the participants lived in single houses rather than apartments. Consequently, the overarching minority of participants resided in their own house. Furthermore, the level of the households' monthly net income was investigated. To compare these results appropriately, the following approach was chosen. First, the upper limits of the income clusters among which participants could select were chosen.

Following an approach recommended by the OECD for equivalence scales (Biewen & Juhasz, 2017), this number was then divided by the square root of the household members. Thereby, the net income per household member was approximated. Over 45 % of the surveyed participants stated that their monthly net income was between 2,000 and 5,000 € per month. Since merely three of the six participants who indicated a monthly net income below 1,000 € signified that they struggled financially to pay their energy bills, this sample size of potential households at risk of energy poverty was too small to derive any significant insights from. The subsequent figure grants an overview of the resulting distribution of respondents' monthly net income.

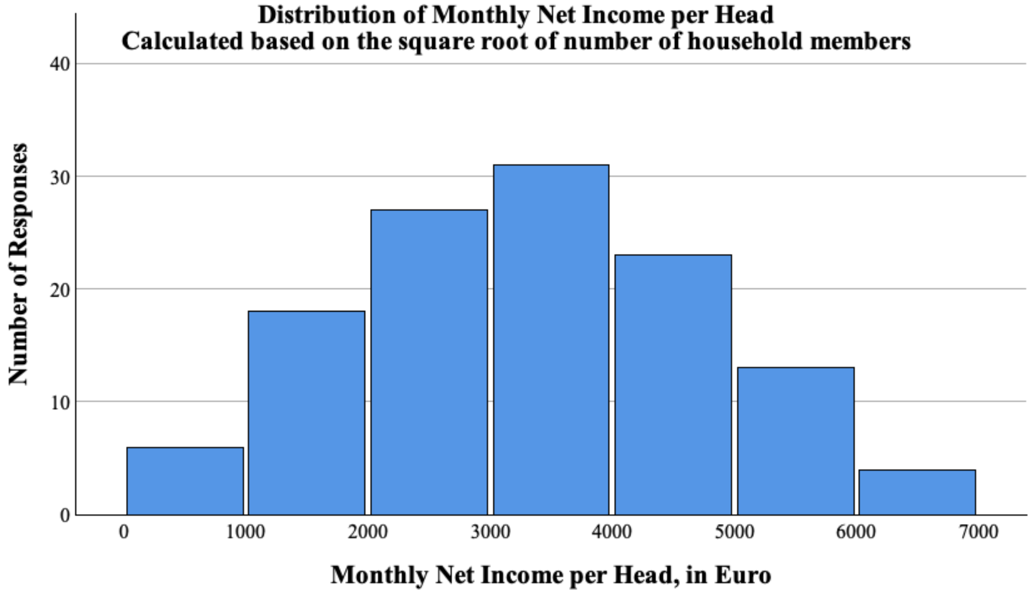

Figure 6.2: Distribution of Monthly Net Income per Household Member

On average, the participants selected five technologies for demand-side flexibility which are in their possession, with over 19 % owning between 8 and 10 such technologies. With over 81 %, 79 %, and 60 % respectively, smart plugs, smart lighting systems, and smart thermostats were the technologies owned by most participants. Approximately half of the participants possessed a smart meter, apps or dashboards for the automatic adjustment of the household's energy consumption as well as rooftop photovoltaic systems. Battery storage systems, heat pumps, and electric vehicle charging stations were chosen by roughly a third of the participants. Constituting to around 25 %, photovoltaic systems on households' balconies were the least common among respondents. A noteworthy tendency in this regard is that the number of technologies owned increased with income.

Suitable to the comparatively high number of technologies for demand-side flexibility in their possession, the participants presented certain tendencies in terms of their approach towards their energy consumption. On average, they stated that they were considerate about their energy consumption and were trying to save energy. Moreover, they tended to be well-informed about digital technologies and their usage and highly agreed that they liked to try out new digital technologies. Averagely, they were aware of the energy consumption of the technologies in their households. They also exhibited a rather high tendency of trust towards the technologies in their households, stating that they did not mind technologies automatically adjusting the energy patterns of their household.

The formerly presented demographics of the participants illustrate that the survey predominantly reached a particular group of society. The average participant was male, middle-aged, middle class, lived in their own house with another person, tended to be digitally literate, exhibited a certain interest about and trust into digital technologies, and owned a comparatively high number of technologies for demand-side flexibility. Considering the results of the first sub-research question, this group exhibited clear demographic disparities compared to households at risk of energy poverty. Therefore, the results of the second sub-research question were interpreted against the background of these demographics.

6.2.2 Spillover Effects associated with the Access to Technologies for Demand-Side Flexibility

To answer the second sub-research question, the level of agreement to questions regarding changes in terms of participants' energy consumption behavior after their adoption of at least one technology for demand-side flexibility were utilized. The vast majority of participants who responded to these questions stated that these technologies enriched the understanding of their energy consumption and made it easier for them to save energy. Furthermore, the results exhibited a clear tendency that the access to technologies for demand-side flexibility significantly contributed to the saving of energy costs for the participants. Over 60 % of the respondents agreed at least partially hat the adoption of technologies for demand-side flexibility resulted in considerations to implement additional technologies for demand-side flexibility and digital technologies in general.

The most significant spillover effects were documented in terms of participants' openness to technological automation as well as in terms of the perceived control and comfort. Around 70 % of the participants agreed partially or fully that the adoption of technologies for demand-side flexibility made them more receptive to the notion of automating their energy consumption through digital technologies. Nearly the same number of respondents stated that the adoption of technologies for demand-side flexibility augmented their feeling of control over their households' energy consumption and made it more comfortable for them to adjust their energy use. Contrastingly, most respondents indicated a strong disagreement with the statement that the adoption of technologies for demand-side flexibility resulted in considerations to insulate their homes in an energy efficient manner. The design of the survey does not permit any definite insights into their reasoning behind this choice. It might, however, be assumed that this is partly because the participants' households were already comparatively thermally efficient.

Overall, the results of the survey predominantly mirrored the experts' statements about the spillover effects. Having not yet directly assessed this topic from neither an academic nor professional perspective, most experts stated, after a short consideration, that the adoption of technologies for demand-side flexibility might result in spillover effects in terms of households' overall energy consumption behavior. Yet, the interviewees acknowledged that these spillover effects depend on further factors. I07 states that, "if [households] are early adopters of these technologies, they are more likely to have [a positive approach towards digital technologies] anyway, but if this was somehow brought to them or introduced to their home, I would think it might encourage them to think and be less intimidated by digital [technologies]" (personal communication, March 8, 2024).

While affirming that the adoption of technologies might result in a change of energy consumption behavior in terms of a shift of energy loads for those with a rather high digital literacy, I08 also raises awareness that such spillover effects might manifest less for other parts of the society, particularly elderly people (personal communication, March 14, 2024). Under consideration of the unrepresentative sampling of the participants, it is assumed that the obtained responses are not fully representative for other parts of the German society either.

Nonetheless, based on these tendencies which were derived from the survey and sustained by the experts' assessment, the second sub-research question was answered as follows: The adoption of technologies for demand-side flexibility is associated with significant spillover effects in terms of households' energy consumption behavior. The access to technologies for demand-side flexibility positively correlates with households' understanding of their energy consumption, the facilitation of energy cost saving, and gives rise to considerations to implement additional technologies for demand-side flexibility and digital technologies in general. Moreover, the adoption of technologies for demand-side flexibility positively correlates with an increased openness to technological automation, control, and comfort for the household members.

Interpreting these spillover effects in reverse paves the way for the identification of central injustices associated with the limited access of households at risk of energy poverty to technologies for demand-side flexibility. It is assumed that their limited access might entail a decreased ability to obtain insights into their energy consumption patterns, potentially resulting in missed opportunities to save energy costs. Furthermore, it might be associated with decreased comfort for household members and an increased reluctance to adopt technologies for demand-side flexibility and digital technologies in general compared to those who already possess such technologies. Therefore, in the longer term, this trajectory might entail that households that do not have access to technologies for demand-side flexibility at this stage of the energy transition might bypass it altogether. While households with said access might expand their suite of technologies gradually, profiting from innovative tariffs and service models, households without it might develop an increased hesitancy towards such technologies. This might result in their structural exclusion from the energy transition. Framed as injustices, these spillover effects are logically consolidated into the results of the main research question.

6.3 Energy Justice Decision-Making Framework

Hereinafter, the injustices associated with the current access of households at risk of energy poverty to technologies for demand-side flexibility are outlined, thereby directly answering the main research question. In accordance with the inductive/deductive hybrid analysis, the structure follows SOVACOOL ET AL.'S (2016) energy justice decision-making framework that has been adjusted according to the research background. The injustices presented below were identified based on the thematic analysis of the expert interviews as well as the analysis of the complementary online survey. Some of the injustices were homogeneously addressed by all experts. However, given the various professional backgrounds of the interviewees, there are also injustices which were raised by a few, yet consistently more than two, interviewees. While three principles have been added, due process has been discarded. Since the thematic analysis did not yield any injustices for which this principle applies, due process was not further elaborated on.

6.3.1 Affordability

Due to its central role in the current literature on demand-side flexibility, affordability represents the first principle from which energy injustices were derived. In the context of households at risk of energy poverty, affordability not only encompasses the financial costs associated with the provision of energy services themselves, but also of technologies for demand-side flexibility. A central injustice in the realm of energy services is related to the current German energy system where fixed energy tariffs prevail. In such a system, the monetary benefits of demand-side flexibility are, particularly for smaller consumers, marginal. Yet, on a system scale, demand-side flexibility already yields benefits; by aligning the generation of energy to its consumption, less redispatch is required which decreases the standing charges and thus energy costs for households in the long term. Hence, households at risk of energy poverty who do not have a lot of flexibility capital to provide might adjust their energy consumption nonetheless to reap economic benefits. I07 describes this by stating, “if you are a [household at risk of energy poverty], then the really small financial gains that are available by being flexible might be meaningful to you in a way that they’re not for a higher-income household” (personal communication, March 8, 2024).

In this context, the experts critically raised awareness that, due to the access to technologies for demand-side flexibility of those more affluent, their financial advantages are comparatively higher and their effort of providing flexibility lower than for households at risk of energy poverty. Hence, the first injustice in the realm of affordability is: *The current marginal monetary benefits of demand-side flexibility might pressure households at risk of energy poverty to provide socially-derived flexibility through which they reap smaller economic gains while putting in more effort than households with access to technologies for demand-side flexibility.* With the progressive introduction of dynamic time-of use tariffs based on the federal spot price and network operators' ability to adjust their grid fees quarter-hourly, the economic benefits of demand-side flexibility are expected to increase, potentially intensifying the previously outlined injustice. This is further discussed under 0.

In terms of the affordability of technologies for demand-side flexibility, it was acknowledged that the costs associated with technologies for demand-side flexibility are significant, largely preventing households at risk of energy poverty from obtaining them. This results in the increasing access of more affluent households to technologies for demand-side flexibility while households at risk of energy poverty are largely unable to afford them. Here, I10 acknowledges that this gradually results in a segment of the society "using old, outdated technologies having to pay more and more for using [them] because they are not benefitting from the newer systems. And that becoming a significant problem over time as more and more people are in the brave new world, but there are those left behind" (personal conversation, March 20, 2024). This translates into the following injustice: *The limited access of households at risk of energy poverty to technologies for demand-side flexibility and their use of outdated, energy-inefficient technologies instead represents an additional financial burden for them.*

This is closely related to an additional injustice in the context of subsidies to obtain technologies for demand-side flexibility. While such subsidies do exist in Germany, they differ between states, regions, and municipalities. Furthermore, existing subsidies do not cover the complete purchase costs which poses another barrier for households at risk of energy poverty to obtain technologies for demand-side flexibility. This is associated with another injustice: *Subsidies for technologies for demand-side flexibility differ among regions and do not fully ensure affordability for households at risk of energy poverty.*

In this context, the experts critically referred to the formerly introduced "energy price brakes" which were initiated by the German government to alleviate energy costs for consumers between 2022 and 2023. Because of the way this scheme was designed, more affluent households with a higher annual energy use did not have to overly restrict themselves to decrease their consumption below the predetermined 80 % threshold. For households at risk of energy poverty whose energy consumption is predominantly dedicated to fulfilling their basic energy needs, the incentivization of such a reduction might only be achievable through a harmful withdrawal from energy services to reap economic benefits. The interviewed experts hence critically stated that the scheme did contribute to the decrease of energy costs for consumers, yet mainly addressed more affluent households and not those most dependent on such an alleviation. Albeit the “energy price brakes” were not directly dedicated to demand-side flexibility but rather the overall saving of energy, the scheme exemplifies the interplay between policy design and energy injustices. This was summarized as: *Current schemes related to the German energy transition might not fully take the measures households at risk of energy poverty undertake to save energy into account, thus not adequately targeting the alleviation of energy costs for them.*

The tables provided at the end of a principle summarize the formerly identified injustices. By delineating each of the injustices associated with the current access of households at risk of energy poverty to technologies for demand-side flexibility, Tables 6.1 until 6.6 serve to comprehensively answer the main research question. Simultaneously, the injustices which reflect on the first and second sub-research question are structured along the corresponding principles and are labelled accordingly. Because the last four principles each encompass a single injustice, they are presented together in Table 6.6 at the end of the chapter. Derived from the first sub-research question, the initial injustice serves as a point of origin for further injustices and is thus presented without a specific principle before summarizing the injustices previously stated under the principle of affordability.

Table 6.1: Overview of Injustices summarized under the Affordability Principle

<table>
<tr><th>Energy Justice Principle</th><th>Injustice</th></tr>
<tr><td colspan="2">Sub-research question 1: Due to factors largely outside of the control of households at risk of energy poverty, among them their limited access to technologies for demand-side flexibility, their contribution to demand-side flexibility is limited which potentially increases their risk of energy poverty even further.</td></tr>
<tr><td rowspan="3">Affordability</td><td>The current marginal monetary benefits of demand-side flexibility might pressure households at risk of energy poverty to provide socially-derived flexibility from which they reap smaller economic gains while putting in more effort than households with access to technologies for demand-side flexibility.</td></tr>
<tr><td>The limited access of households at risk of energy poverty to technologies for demand-side flexibility and their use of outdated, energy-inefficient technologies instead represents an additional financial burden for them.</td></tr>
<tr><td>Subsidies for technologies for demand-side flexibility differ among regions and do not fully ensure affordability for households at risk of energy poverty.</td></tr>
</table>

Energy Justice Principle	Injustice
	Current schemes related to the German energy transition might not fully take the measures households at risk of energy poverty undertake to save energy into account, thus not adequately targeting the alleviation of energy costs for them.

6.3.2 Availability

Encompassing aspects around households' access to energy services, technologies, and tariffs, the second principle of the energy justice decision-making framework is availability. A central characteristic of technologies for demand-side flexibility is that, if operated in the right way, they contribute to energy service security. Households with a suite of technologies such as photovoltaics and batteries are to a lesser extent affected by power cuts and thus more independent from the energy grid, the experts acknowledged. Correspondingly, *the limited access to technologies for demand-side flexibility potentially leads to a lower level of energy security for households at risk of energy poverty.*

An additional injustice in this nexus is related to the limited choice of households at risk of energy poverty to obtain new energy tariffs. According to the interviewed experts, energy supply companies tend to carry out credit checks, often refusing new customers from neighborhoods with a high share of low-income households. This yields the following justice concern: *Households at risk of energy poverty tend to face structural barriers obtaining new energy tariffs which inhibits them from accessing innovative service models for demand-side flexibility.* Correspondingly, Table 6.2 summarizes the identified injustices of the second principle.

Table 6.2: Overview of Injustices summarized under the Availability Principle

Energy Justice Principle	Injustice
Availability	The limited access to technologies for demand-side flexibility potentially leads to a lower level of energy security for households at risk of energy poverty.
	Households at risk of energy poverty tend to face structural barriers obtaining new energy tariffs which inhibits them from accessing innovative service models for demand-side flexibility.

6.3.3 Transparency and Accountability

The third principle, transparency and accountability, highlights a further central aspect of technologies for demand-side flexibility, namely the information consumers are able to obtain through them. The experts homogenously stated that particularly smart meters, smart plugs, and smart thermostats serve as tools to inform households about their current use of energy. These technologies are relevant for households at risk of energy poverty for various reasons. As they regularly live in rented homes, said households tend to have fewer insights into and thus difficulties comprehending their energy bills and the main contributors thereof. The lack of information about their energy consumption bears the risk of additional payments. Furthermore, households at risk of energy poverty tend to possess less energy-efficient household appliances and live in buildings with poor insulation. These two factors potentially increase energy costs, yet households at risk of energy poverty have limited insight into.

I05 summarizes that such technologies provide further insights into the energy consumption of a household and its appliances to recognize and develop a feeling for the energy they require, at best resulting in the realization that an appliance is energy inefficient and should thus be replaced (personal communication, 6 March, 2024). I01 further elucidates that such technologies also serve educational purposes. “The provision of information about one’s own consumption, but also about the energy system, creating this awareness, is relevant for anyone but especially for those who cannot utilize the technological component to the full” (I01, personal communication, 29 February, 2024).

Amidst the progressing energy transition accompanied by the expansion of innovative technologies and dynamic time-of-use tariffs, such information becomes increasingly relevant for consumers. Closely related to the results obtained through the second sub-research question, this yields the following injustice: *Households at risk of energy poverty with limited access to technologies for demand-side flexibility lack insights into their own energy consumption and the current situation in the energy system.*

Furthermore, the design and implementation of German subsidies dedicated to technologies for demand-side flexibility nurtures further justice implications in the realm of transparency and accountability. The application for such subsidies is bureaucratic, time-consuming, articulated in complex terminology, and sets high requirements for applicants, I09 and I11 remark. For households at risk of energy poverty, this represents an additional barrier. Moreover, several German subsidy programs were ceased at short notice in the past as the funding was depleted earlier than anticipated, causing risks for consumers who then hesitated to retrofit their households altogether (I09, personal communication, 14 March, 2024). This means that *the complex application procedure and lack of consistency* *regarding subsidies might hinder the access of households at risk of energy poverty to technologies for demand-side flexibility, either directly or through their landlord or landlady.* Table 6.3 provides an overview of the injustices identified in the nexus of transparency and accountability while drawing a direct connection to the second sub-research question.

Table 6.3: Overview of Injustices summarized under the Transparency and Accountability Principle

Energy Justice Principle	Injustice
Transparency and accountability	Households at risk of energy poverty with limited access to technologies for demand-side flexibility lack insights into their own energy consumption and the current situation in the energy system (sub-research question 2).
	The complex application procedure and lack of consistency regarding subsidies might hinder the access of households at risk of energy poverty to technologies for demand-side flexibility, either directly or through their landlord or landlady.

6.3.4 Sustainability and Intragenerational Equity

The principle of sustainability is closely related to the formerly discussed spillover effects in the realm of households' energy saving behavior. As illustrated successively, the principle also overlaps with the realm of intragenerational equity under which injustices rooted in socio-economic differences were summarized. Thus, the principles are presented together. In this context, a central difference between households at risk of energy poverty and more affluent ones, namely their level of home insulation. The experts unanimously stated that households at risk of energy poverty tend to live in thermally inefficient homes with poor insulation. This directly reflects on a households' flexibility capital. "If the home is thermally efficient, it will store that energy [similar to] what a battery's doing. The home is storing energy and is releasing it as a thing of value, such as warmth, to the household at a time that they want it. And if the home is well insulated, that will work and then you could switch the heat pump off for some time when the grid needs to and the house will stay warm", I07 specified (personal communication, March 8, 2024). Consistent with the findings obtained through the first sub-research question, *the rather thermally inefficient housing stock of households at risk of energy poverty might negatively affect their ability to contribute to demand-side flexibility* describes an injustice from a sustainability and an intragenerational equity perspective.

This directly relates to a further difference, even among households at risk of energy poverty, is related to whether their home belongs to the public or private rental sector. I03 describes that "we see in the social rental sector sort of involuntary early adopters of some of these technologies [for demand-side flexibility], people that haven't necessarily chosen to get them but their landlord has decided they would be a good thing and there is funding available, so they have been installed […] because you've got relatively few large entities making strategic decisions around that and they have a social responsibility" (personal communication, March 5, 2024). Contrastingly, in the private rental sector, funding programs do exist, but the introduction of new technologies is oftentimes hampered by a lack of willingness from the landlord or landlady, the experts remark. I07 summarizes this by stating that, oftentimes, "[t]he landlord isn't living in the property or paying their energy bill, so they have no incentive to upgrade it, so you get caught in the classic split incentives problem with private rental that is very difficult to overcome. That is the sector with most precarity where people are low income, they have little power to improve their property and the landlord isn't improving it because there's nobody to make them improve it" (personal communication, March 8, 2024). This translates into the following injustice: *The adoption of technologies for demand-side flexibility as well as the implementation of technologies for demand-side flexibility and energy efficiency measures differs between the social and private rental sector, with private landlords and landladies oftentimes hesitating to undertake the associated renovations.*

A further noteworthy aspect in the nexus of intragenerational equity is closely related to the concept of recognition justice. Through the expert interviews, it became evident that representatives and decisionmakers of stakeholders in the energy system, for instance from energy companies and grid operators, are not yet fully attuned to the notion of energy poverty in Germany. This might manifest in various forms, either through a lack of acknowledgement for the financial burden the energy prices have on some households, or through the perception that energy poverty is merely rooted in the inefficient, uneconomic use of energy. Such lack of awareness bears the risk of establishing itself in the energy system of the future, thereby overlooking the impact the design of tariffs and schemes as well as the expansion of digital technologies has for households at risk of energy poverty. *Not all stakeholders in the energy sector fully recognize energy poverty as a structural problem in Germany which might prevent them from taking it into account in their decision-making* thus demarcates an injustice. In line with the previous principles, Table 6.4 summarizes the injustices in the context of sustainability and intragenerational equity while drawing a connection to the first sub-research question. Therefore, the two injustices which apply in the realm of both sustainability and intragenerational equity are presented together, whereas the injustice which merely pertains to the principle of intragenerational equity is outlined separately.

Table 6.4: Overview of Injustices summarized under the Sustainability and Intragenerational Equity Principles

Energy Justice Principle	**Injustice**
Sustainability and intragenerational equity	The rather thermally inefficient homes of households at risk of energy poverty might negatively affect their ability to contribute to demand-side flexibility (sub-research question 1).
	The adoption of technologies for demand-side flexibility as well as the implementation of technologies for demand-side flexibility and energy efficiency measures differs between the social and private rental sector, with private landlords and landladies oftentimes hesitating to undertake the associated renovations.
Intragenerational equity	Not all stakeholders in the energy sector fully recognize energy poverty as a structural problem in Germany which might prevent them from taking it into account in their decision-making.

6.3.5 Intergenerational Equity

Under the sixth principle, intergenerational equity, injustices which are expected to manifest themselves in the energy system of the future are presented. This principle applies to the gradual introduction of dynamic time-of-use tariffs. These tariffs serve as a mechanism to shift demand in time through price signals, for instance increasing the price of energy when demand is particularly high or renewable energy is scarce. However, the ability of households to react to such price signals and adjust their consumption accordingly, varies. Thereby, the experts acknowledged that such tariffs yield particular implications for households at risk of energy poverty.

A fundamental component necessary for any such tariffs is an interface between the households' energy consumption and the grid operators to enable the communication of energy prices and flexible billing. This interface is usually a smart meter which is installed in consumers' households to serve the formerly stated purposes. The current German legislation prioritizes the rollout of smart meters to households above a certain annual energy consumption. While such a prioritization is appropriate from an energy systems perspective, it structurally excludes households at risk of energy poverty as they regularly fall below this threshold. This results in their comparatively late adoption of smart meters which embodies an added entry barrier for the adoption of further technologies for demand-side flexibility. The corresponding injustice is hence summarized as: *The current*

German legislation for the rollout of smart meters as stipulated in the Gesetz zum Neustart der Digitalisierung der Energiewende *bears the risk of structurally excluding households at risk of energy poverty which might impede them from adopting further technologies for demand-side flexibility and innovative energy tariffs in the future.*

I10 elaborates on a further injustice associated with dynamic time-of-use tariffs: “The risk is that those households [who are not able to take advantage of them] get penalized if they cannot move their consumption away from the peak period. Particularly if the differentiation in pricing is very strong, then they can get a real harmful effect from that. And the danger is that if it is […] households already in [energy] poverty that are being penalized by the system that is imposed on them, if it is something that becomes a general structuring effect of the energy market” (personal communication, March 20, 2024).

Said risk associated with dynamic time-of-use tariffs might be even further exacerbated by an effect increasingly seen in strained systems, namely surge pricing. An example thereof is the taxi service Uber whose prices drastically rise during peak times of demand. With dynamic time-of-use tariffs, energy prices might undergo similar surges. This is particularly challenging for households on a tight budget who require an energy bill without major fluctuations rather than a tariff where risk is involved. This brings forth a further injustice, namely: *Because the ability of households to react to price signals partially depends on their access to technologies for demand-side flexibility, dynamic time-of-use tariffs might bear a disproportionate risk of penalizing households at risk of energy poverty*.

The last injustice under the principle of intergenerational equity addresses the gradual electrification of the energy system. As households are increasingly switching over to electric heating, the financial costs of maintaining the fossil fuel infrastructure will be paid by those still using it. While more affluent households are leapfrogging to electric solutions, households in the private rental sector and particularly those at risk of energy poverty will initially stay in the fossil fuel infrastructure, paying increasingly more as the costs are split between fewer consumers. A further factor which plays into this is the transition from the national to the European Emissions Trading System which enables the auctioning of emissions with free prices on the market from 2027 onwards. According to expert I06, such a carbon emissions trade might result in the increase of energy prices for fossil fuels. Accordingly, *because of the limited access to technologies for demand-side flexibility, households at risk of energy poverty might bear the disproportionate costs of the fossil fuel infrastructure for longer.* Table 6.5 provides an outline of the previously discussed injustices.

Table 6.5: Overview of Injustices summarized under the Intergenerational Equity Principle

Energy Justice Principle	**Injustice**
Intergenerational equity	The current German legislation for the rollout of smart meters as stipulated in the *Gesetz zum Neustart der Digitalisierung der Energiewende* bears the risk of structurally excluding households at risk of energy poverty which might impede them from adopting further technologies for demand-side flexibility and innovative energy tariffs in the future.
	Because the ability of households to react to price signals partially depends on their access to technologies for demand-side flexibility, dynamic time-of-use tariffs might bear a disproportionate risk of penalizing households at risk of energy poverty.
	Because of the limited access to technologies for demand-side flexibility, households at risk of energy poverty might bear the disproportionate costs of the fossil fuel infrastructure for longer.

6.3.6 Responsibility

While SOVACOOL ET AL.'S (2016) principle of responsibility mainly addresses nations as a whole, the analysis of the interviews put further stakeholders into the focus. In the realm of households at risk of energy poverty, these include, first and foremost, landlords and landladies. As previously stated, said households typically live in rented homes. This bears the possibility that the implementation of technologies for demand-side flexibility does not necessarily ensure that households are able to operate them flexibly and according to their requirements. This is particularly the case for heat pumps, as the experts consistently stated. I04 elaborates that, since the landlord or landlady is responsible for installing and setting up the heat pump, households “might lose that communication opportunity of setting it up in a way that works for them and their lifestyle, with flexibility considered” (personal communication, March 6, 2024). If not implemented appropriately, the technology bears the risk of increasing the financial burden of households, forcing them to operate it at an unhealthily low temperature, or simply not providing any flexibility to the grid.

This also illustrates a significant feature of technologies for demand-side flexibility. As is the case for heat pumps, such technologies lay the foundation for demand-side flexibility, yet they do not necessarily ensure their flexible operation. The associated injustice is that *the installation of technologies for demand-side flexibility is often the responsibility of landlords and landladies which might inhibit households at risk of energy poverty to adjust them according to their own requirements and operate them flexibly.*

6.3.7 Comfort

Just like the following two principles, comfort was not part of the initial energy justice decision-making framework but was derived inductively from the interview data as well as the complementary online survey. Based on the former, it became evident that demand-side flexibility is associated with a certain level of discomfort for households as it might involve the adjustment of their energy consumption patterns. Yet, households who have access to technologies for demand-side flexibility and are also able to operate them in such a way that serves their needs while still granting flexibility to the grid, are to a lesser extent confronted with discomfort. I07 further expands this notion by stating that, "if you have a suite of technologies, if you own a home that has solar panels, an electric vehicle and smart white goods, then you can configure them in such a way that they can serve the grid without any inconvenience to you, and you might even benefit because you'll be taking the advantages of better tariffs and charging your car at night and using photovoltaics when it is most optimal" (personal communication, March 8, 2024).

Contrastingly, as households at risk of energy poverty typically lack access to such a suite of technologies, they might opt to contribute through manual actions, with socially-derived flexibility, in anticipation of small financial benefits. Socially-derived flexibility does not necessarily have to be unjust; it might however be accompanied by what I07 describes as a situation where households "start to self-impose some limitations and some inconveniences and potentially some kind of harmful withdrawal from the grid at certain times. It might just be that your mealtimes and therefore important times to socialize and spend time with family become things that might move in time or might no longer happen. Whereas a household for whom that small price signal is insignificant, will just continue unaffected, really. Which does them no harm. But it doesn't deliver the grid any flexibility. So that's also suboptimal" (personal communication, March 8, 2024). Mirroring the results of the second sub-research question, this illustrates that, *due to their limited access to technologies for demand-side flexibility, households at risk of energy poverty might resort to socially-derived flexibility which is potentially associated with discomfort, social isolation, and the alteration or dismissal of households' usual social practices*.

6.3.8 Resource Man

Similar to the previous principle, the Resource Man was added to the original energy justice decision-making framework. The Resource Man was originally introduced by

STRENGERS (2014) who challenges the notion of the smart energy consumer as someone with a central role in the digitalization of the energy sector. She states that such a Resource Man, as envisioned by the – male-dominated, hence the name – energy industry, "responds rationally to price signals and makes informed decisions based on up-to-date and detailed data provided about costs, resource units […], and [environmental] impacts of his consumption, dynamic prices, and enabling technologies […] which allow him to transform his home into a resource control station. He is both in control of his energy consumption and assigns this control to technologies to manage on his behalf" (p. 25).

With that, STRENGERS (2014) critically recognizes that this perception of the energy consumer overlooks the daily social activities in a household and applies merely to a specific clientele. This research builds on this notion through the consideration that demand-side flexibility and the accompanying technologies add to households' daily lives like an additional chore. This is based on the acknowledgement that socially-derived, but also technology-derived flexibility takes up households' headspace, either through manual actions or the configuration of technologies in a way that suits their lifestyle. It acknowledges that the physical and mental capacity they dedicate to their energy consumption on top of their everyday responsibilities is limited. This rationale is conceptualized through the Resource Man. He is particularly applicable to households at risk of energy poverty. As illustrated in subchapter 6.1, these households tend to be confronted with complex, multifaceted problems and burdens, significantly limiting their flexibility capital. In the context of socially-derived flexibility, this might lead to households' increasing concern about not only the amount of energy they use, but the time they are using it, potentially overburdening them.

The Resource Man, moreover, also applies to technology-derived flexibility. I04 critically acknowledges that demand-side flexibility puts households in a position where they are expected "to become a technology expert, an energy markets expert, even an expert on energy tariffs, because there are energy tariffs that are getting much more difficult to understand now" (personal communication, March 6, 2024). This is particularly challenging for those with a limited digital literacy such as elderly people since energy companies increasingly communicate digitally with their customers. The Resource Man thus epitomizes the following injustice: *Contributing to demand-side flexibility through either social or technological means might add a further concern to the daily life of households at risk of energy poverty, bearing the risk of overburdening them.* The notion of the Resource Man is thus a noteworthy consideration in the design of technologies and schemes, for households at risk of energy poverty but also beyond that.

6.3.9 The Social License to Automate

The last principle of the energy justice framework which was inductively derived is called the social license to automate. The term originates from what has been coined a social license to operate, used to describe the social requirements necessary to ensure the success of and prevent resistance against projects which involve the restructuring of the natural environment (Adams et al., 2021). Based on this concept, the social license to automate acknowledges that users have an active participatory role in the automation of demand-side management and are thus crucial for its successful development (Adams et al., 2021). In the scope of this research, the term was used to operationalize the conditions which constitute to households' acceptance of the automation for demand-side flexibility.

The concept does not fully apply to the predominantly manual contributions of households at risk of energy poverty to demand-side flexibility in today's energy system. However, it plays a central role for technology-derived flexibility which ultimately culminates in technological automation and interoperability. In the context of this research, the social license to automate addresses the extent to which households at risk of energy poverty are willing to automate their demand-side flexibility once the access to respective technologies is given. If households grant said license, they are essentially open to disclose their individual preferences in terms of electricity and heating to a third party who then ensures that, considering these parameters, the household automatically provides flexibility to the grid while benefitting from affordable energy prices.

Albeit the social license to automate includes a future component as the expansion of said technologies is, particularly for households at risk of energy poverty, still in its early stages and the formerly mentioned third parties are just entering the market, it is nonetheless a noteworthy aspect in today's energy system to ensure that sources of resistance are addressed in a preventive manner. In this context, the experts critically acknowledged that households at risk of energy poverty might exhibit a stronger tendency to refuse granting the social license to automate. There are various reasons for their reluctance, ranging from surveillance and privacy concerns and limited awareness, to – first and foremost – the currently limited access to such technologies. According to the interviewed experts, the acceptance of automation is closely related to households' exposure to them.

In other words, a positive experience with technologies for demand-side flexibility over a prolonged period might contribute to the increase of trust which, in turn, contributes to an increased willingness to grant the social license to automate. Closely in line with the results of the spillover effects from the second sub-research question, this translates into a further injustice, namely that *the limited access of households at risk of energy poverty to technologies for demand-side flexibility might result in their reluctance or resistance* *to grant the social license to automate.* As previously stated, since the last four principles were each associated with a single injustice, they are presented together in the following table while drawing a connection to the second sub-research question. The last injustice was directly identified based on the results of the second sub-research question and summarizes the implications of the spillover effects for households at risk of energy poverty on the energy transition in the long term. Given its fundamental character, the injustice was not structured along a particular energy justice principle but instead serves as a conclusion to the energy justice decision-making framework. With that, the main research question has been answered.

Table 6.6: Overview of Injustices summarized under the Principles of Responsibility, Comfort, the Resource Man, the Social License to Automate, and the Spillover Effects

<table>
<tr><th>Energy Justice Principle</th><th>Injustice</th></tr>
<tr><td>Responsibility</td><td>The installation of technologies for demand-side flexibility is often the responsibility of landlords and landladies which might inhibit households at risk of energy poverty to adjust them according to their own requirements and operate them flexibly.</td></tr>
<tr><td>Comfort</td><td>Due to their limited access to technologies for demand-side flexibility, households at risk of energy poverty might resort to socially-derived flexibility which is potentially associated with discomfort, social isolation, and the alteration or dismissal of households' usual social practices (sub-research question 2).</td></tr>
<tr><td>Resource Man</td><td>Contributing to demand-side flexibility through either social or technological means might add a further concern to the daily life of households at risk of energy poverty, bearing the risk of overburdening them.</td></tr>
<tr><td>Social license to automate</td><td>The limited access of households at risk of energy poverty to technologies for demand-side flexibility might result in their reluctance or resistance to grant the social license to automate (sub-research question 2).</td></tr>
<tr><td colspan="2">Sub-research question 2: The spillover effects associated with the adoption of technologies for demand-side flexibility might result in the structural exclusion of households at risk of energy poverty with limited access to such technologies from the energy transition in the long term.</td></tr>
</table>

7 Discussion

The previously presented findings encourage the critical exploration of further aspects in the realm of the research background. Therefore, the following chapter addresses the broader implications associated with the results of this paper while drawing a connection to the scientific literature on which this research builds. Taking the energy justice decision-making framework literally, the chapter concludes with a proposal of solutions through which the identified injustices might be tackled in a practice-oriented manner.

7.1 From the Results back to the Literature: A Synthesis

The results of the first sub-research question bore an overview of central characteristics which contribute to households' risk of energy poverty. These include their housing situation, where the social and particularly private rental sector increases the risk of energy poverty. Furthermore, children, particularly single parenthood, the employment status, limited knowledge about energy saving measures, as well as the existence of complex personal problems and strokes of fate contribute to the risk of energy poverty. This also applies to low-income households and those receiving social benefits. Lastly, the equipment with energy inefficient household appliances as well as unemployment and retirement represent frequent characteristics of households at risk of energy poverty.

These characteristics reflect on the existing body of scientific literature on energy poverty in Germany from authors such as KOPATZ ET AL. (2010), TEWS (2013), GROßMANN (2017), KAHLHEBER (2017), and, most recently, BODE (2022). Strikingly, the authors' findings about the characteristics of households at risk of energy poverty over the years still apply, to a substantial extent, in today's energy system. Based on this, the first sub-research question extends the German discourse around energy poverty by addressing the topic from the perspective of demand-side flexibility.

Due to factors largely outside of their control such as the housing situation as well as their limited financial ability to invest in technologies for demand-side flexibility, households at risk of energy poverty have limited access to such technologies. These characteristics, in turn, significantly limit their ability to contribute to demand-side flexibility. This leads to a mutual interdependency; the characteristics of households at risk of energy poverty limit their ability to contribute to demand-side flexibility, and their limited contribution to demand-side flexibility might further exacerbate their risk of energy poverty. Based on these insights, it was concluded that the contribution of households at risk of energy poverty to demand-side flexibility is small. It was, however, recognized that a significant proportion of these households still contributes to demand-side flexibility through socially-derived flexibility as well as through digital technologies, if available.

The second sub-research question investigated the spillover effects which are associated with the access of households to technologies for demand-side flexibility on their energy consumption behavior. Therefore, the online survey dedicated to answering this question directly addressed households who already possess at least one such technology. The results of this question contributed to fundamental insights into the demographics of early adopters of technologies for demand-side flexibility. These characteristics, particularly their tendency to be rather affluent, reside in their own house with one other adult, accompanied by their control and agency over the implementation of technologies for demand-side flexibility clearly demarcated them from households at risk of energy poverty. This was also mirrored in their possession of, on average, five technologies for demand-side flexibility.

Under consideration of these demographics, tendencies of significant spillover effects associated with the access of households to technologies for demand-side flexibility on their energy consumption behavior were analyzed. In other words, the access to technologies for demand-side flexibility resulted in households' changes in their energy consumption, increasing their understanding thereof, contributing to their personal comfort, and positively influencing their overall approach towards digital technologies. This trajectory might have fundamental consequences for the long-term participation of households at risk of energy poverty in the energy transition. Due to their limited access to technologies for demand-side flexibility, these spillover effects do not apply for these households. This might manifest itself in the progressing energy transition, structurally leaving parts of the society behind. This thus represents a clear reasoning to decrease access barriers for households at risk of energy poverty to technologies for demand-side flexibility despite their comparatively limited contribution to demand-side flexibility. Apart from the associated injustices on a household scale, this might also impede the energy transition in the long term whose successful progress is, as outlined by authors such as DÜTSCHKE ET AL. (2019) and BOSCH & SCHMIDT (2020), dependent on social acceptance.

These characteristics as well as the identified spillover effects closely correspond and further expand the conceptual assessment of POWELLS & FELL (2019) who state that more affluent households with a comparatively higher flexibility capital experience opportunities to decrease their energy costs through technology-derived flexibility without the loss of comfort. Furthermore, the dichotomy between households who already possess technologies for demand-side flexibility and those at risk of energy poverty exemplifies the manifold distributional justice considerations the research touched upon. In the nexus of the identified spillover effects, these considerations incorporate the distribution of ills as well as the re-distribution of benefits. According to JENKINS ET AL. (2016), the latter encompasses the unfair proliferation of benefits due to the energy transition. The re-distribution of benefits is thus discernible in the spillover effects associated with the access to technologies for demand-side flexibility such as increased comfort and energy saving. The distribution of ills refers to the relatively higher costs those with a lower income are potentially confronted with in the energy transition. Conversely, this notion is reflected in the non-applicability of the spillover effects for households at risk of energy poverty due to their limited access to technologies for demand-side flexibility.

The main research question provided a holistic overview of the injustices associated with the current access of households at risk of energy poverty to technologies for demand-side flexibility under incorporation of the two sub-research questions. The energy justice decision-making framework by SOVACOOL ET AL. (2016) served as the theoretical framework; operationalized for the research background, the energy justice principles functioned as the basis for the identification of injustices. Through expanding, merging, and omitting these principles accordingly, twenty injustices structured along ten energy justice principles were identified.

Despite their predominantly separate presentation, the principles demonstrate clear relations among them. Particularly the notion of affordability surpassed the first principle and was included in the principles of transparency and accountability, as well as intergenerational equity. Furthermore, the Resource Man as well as the social license to automate have a clear future component to them. As such, both components belong in the sphere of the principle of intergenerational equity. Moreover, the social license to automate represents a possible solution to the Resource Man. The automation of demand-side flexibility through technologies potentially decreases the burden the Resource Man faces in his endeavor to contribute to demand-side flexibility. As has been further illustrated through the merging of sustainability and intragenerational equity, the energy justice decision-making framework leaves room for interpretation; some injustices touch upon multiple principles whereas others build on each other.

Even though the energy justice decision-making framework was deployed as the theoretical framework of this research, central aspects of the results coincide with the types of energy justice outlined in the literature review, particularly the triumvirate of tenets. Since the overarching topic of energy poverty is closely intertwined with the notion of distributional justice, the identified injustices homogenously exhibit characteristics of the first tenet. Moreover, the distribution of ills closely reflects on the principle of affordability, whereas the re-distribution of benefits is inherent, for instance, in the principle of intergenerational equity where dynamic time-of-use tariffs might yield financial benefits for households who are able to react to price signals.

Frequently presented as the second tenet, recognition justice aims to identify those affected by energy injustices, calling for respect and equal rights. Under the principles of sustainability and intragenerational equity, it was analyzed that there are still stakeholders in the German energy sector who do not fully recognize energy poverty as a structural problem. In this context, the interviewed experts predominantly referred to stakeholders' failure to acknowledge the existence of such a phenomenon which reflects on an injustice conceptualized by JENKINS ET AL. (2016) as non-recognition. However, it also incorporated the notion of disrespect towards households at risk of energy poverty as experts stated their experience of stakeholders' opinion that energy poverty was merely rooted in households' uneconomic use of energy. In accordance with authors such as GALVIN (2019), the applied framework also acknowledges the temporal dimension of energy justice, particularly through the principle of intergenerational equity.

As the last of the triumvirate of tenets, procedural justice is aimed at the provision of strategies to tackle energy injustices. Albeit outside of the scope of the research questions, the identification of injustices according to the energy justice decision-making framework can serve as the foundation to develop such strategies. Using the energy justice decision-making framework according to its title, the ensuing subchapter proposes potential solutions based on the narrative of the identified injustices. Hence, while still incorporating notions of the more abstract types of energy justice, particularly distributional, recognition, and procedural justice, the framework by SOVACOOL ET AL. (2016) enabled a more holistic and practice-oriented approach towards energy justice.

7.2 From Energy Injustices to Decision-Making: A Way Forward

SOVACOOL ET AL. (2016) introduce the energy justice decision-making framework as a tool to facilitate the discourse around energy injustices between researchers, practitioners, and energy consumers. As evident through its title, said framework might serve as the basis for the identification of decisions. Correspondingly, the ensuing subchapter proposes potential solutions which are intended to address central injustices identified through the framework. Through the interviews with experts from various backgrounds, the discourse around injustices was frequently followed by recommendations to address them. Therefore, applying a similar approach to the one presented by SOVACOOL & DWORKIN (2015), this subchapter demonstrates the utilization of the narrative about injustices to derive solutions. Based on four chosen injustices, exemplary potential solutions which were touched upon throughout the expert interviews are discussed hereinafter. For each of them, a time span has been granted to illustrate that the solutions partially build on each other and depend on the gradual progress of the energy transition.

The first injustice which serves as an example for the identification of solutions stems from the second sub-research question and addresses the potential risk of structurally excluding households at risk of energy poverty from the energy transition due to the identified spillover effects. A potential solution thereof is the gradual introduction of said households to technologies for demand-side flexibility through existing regional contact points such as the consumer advice centers and the *Stromspar-Check*. Albeit they already provide advice and energy-saving technologies free of charge for households at risk of energy poverty, technologies for demand-side flexibility do not play a central role in their projects yet.

Throughout the next years, technologies with small investment costs and without the requirement of major installations which necessitate the involvement of landlords and landladies, for instance smart plugs and smart thermostats, could be included in the portfolio of the energy consultations. Thereby, the gradual access of interested households at risk of energy poverty to such technologies can be facilitated which might result in positive spillover effects on their energy consumption behavior and thus contribute to their participation and inclusion in the energy transition.

Furthermore, it was analyzed that the current legislation *Gesetz zum Neustart der Digitalisierung der Energiewende* for the rollout of smart meters in Germany potentially excludes households at risk of energy poverty. This might inhibit them from adopting further technologies for demand-side flexibility as well as corresponding energy tariffs in the future. To address this injustice, the rollout of smart meters to smaller consumers should be significantly accelerated, for instance by coupling the administration and implementation to the Act for Renewable Heating (*Wärmeplanungsgesetz*).

This is closely related to the third injustice that could be addressed right away but is associated with a long execution period, namely the thermally inefficient housing stock which negatively influences households' ability to contribute to demand-side flexibility. The expansion of subsidy programs for the thermal insulation of the German building stock represents a potential solution thereof. To ensure that these subsidies reach households at risk of energy poverty, the renovation of buildings with a particularly low thermal efficiency should be prioritized. Simultaneously, these programs should be administered in a way that grants renovators a level of financial security, preventing the premature depletion of funding.

The last injustice used to spark discussions around energy justice considerations is associated with the introduction of dynamic time-of-use tariffs. Since these tariffs are gradually entering the German energy system, it is anticipated that their introduction to households at risk of energy poverty will require a longer time horizon, particularly because the existence of a smart meter is a prerequisite. As previously elaborated, such tariffs are associated with significant risks of penalizing households unable to adjust their energy consumption accordingly. Therefore, the introduction of social tariffs represents a possible solution which might grant households at risk of energy poverty access to such innovative tariffs while alleviating their energy costs. Following the recommendation of I07, such social tariffs could be designed in a "progressive" manner. Depending on the household size and the thermal efficiency of the building, households are granted a particularly cheap tariff rate which covers their basic energy needs. Once this fundamental threshold is exceeded, the rate increases as households choose to consume energy beyond their basic needs. Such a tariff could be designed under consideration of the energy efficiency standards to account for the increased energy needs of poorly insulated buildings (S. Thomas et al., 2021).

The following figure exemplifies the contextualization of such a progressive social tariff through the size of the household and the energy efficiency rating. The grey dashed blocks illustrate the social tariff rates for a household consisting of less members and living in a more thermally efficient building than the household for which the white blocks would apply. The first block represents the energy required to account for households' basic energy needs which is thus associated with the lowest energy price tariff; since the second and third block surpass this threshold, progressively higher energy prices are employed.

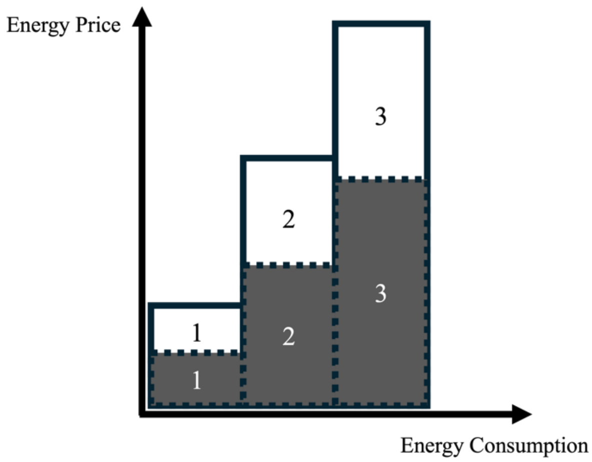

Figure 7.1: Illustration of a "Progressive" Social Tariff

Against this background, Table 7.1 provides a summary of the previously discussed injustices and solutions including their anticipated time spans. Thereby, the potential of using the energy justice decision-making framework to discuss solutions to energy injustices among different stakeholders is illustrated.

Table 7.1: Overview of Selected Injustices and Potential Solutions

Injustice	**Potential Solution**	**Time Span**
The spillover effects associated with the adoption of technologies for demand-side flexibility might result in the structural exclusion of households at risk of energy poverty with limited access to such technologies from the energy transition in the long term.	Gradually introduce households at risk of energy poverty to technologies for demand-side flexibility with small investment costs such as smart plugs and smart thermostats through consumer advice centers and the *Stromspar-Check.*	Short-term
The current German legislation for the rollout of smart meters as stipulated in the *Gesetz zum Neustart der Digitalisierung der Energiewende* bears the risk of structurally excluding households at risk of energy poverty which might impede them from adopting further technologies for demand-side flexibility and innovative energy tariffs in the future.	Accelerate the rollout of smart meters to smaller consumers to pave the way for further technologies for demand-side flexibility by coupling it to the Act for Renewable Heating (*Wärmeplanungsgesetz*).	Short- to medium-term
The rather thermally inefficient housing stock of households at risk of energy might negatively affect their ability to contribute to demand-side flexibility.	Expand subsidy programs for the thermal insulation of old housing stock across Germany with the prioritization of particularly thermally inefficient buildings. Administer programs in a way that ensures financial security for renovators.	Short- to long-term
Because the ability of households to react to price signals partially depends on their access to technologies for demand-side flexibility, dynamic time-of-use tariffs might bear a disproportionate risk of penalizing households at risk of energy poverty.	Introduce “progressive” social tariffs under consideration of the energy efficiency of buildings and the household composition.	Medium- to long-term

8 Conclusion

Representing the final part of this paper, the following chapter briefly summarizes the research findings before providing an outline of the result's transferability into other contexts. Central limitations as well as associated further avenues of research constitute the end of this paper.

8.1 Summary

This paper's research goal was to expand the discourse around the injustices associated with the current access of households at risk of energy poverty to demand-side flexibility in the context of Germany. To support energy decision-making among different stakeholders, these injustices were intended to be multifaceted, empirical, and future-oriented. The first step thereof was to broaden the currently scarce academic discourse on energy poverty by outlining the contribution of households at risk of energy poverty to demand-side flexibility in Germany. Furthermore, to identify potential injustices in the longer term, the research intended to assess the spillover effects on households' energy consumption behavior associated with the access to technologies for demand-side flexibility.

Therefore, two sub-research questions and a main research question were formulated. The first sub-research question addressed the contribution of households at risk of energy poverty to demand-side flexibility. Despite the lack of insights from households at risk of energy poverty themselves, the interviewed experts granted a comprehensive answer to this question. Therefore, central household characteristics which contribute to the risk of energy poverty were outlined first. Based on these characteristics, it became evident that the contribution of these households to demand-side flexibility is limited, mainly due to factors outside of the households' control. One of these factors is their limited access to technologies for demand-side flexibility. Simultaneously, the mutual interdependency among households' limited contribution to demand-side flexibility and the risk of energy poverty was illustrated.

The second sub-research question addressed the spillover effects associated with the access of households to technologies for demand-side flexibility on their energy consumption behavior. This question was primarily answered through a quantitative online survey and triangulated with statements from the expert interviews. Based on their assessment and 133 survey responses, it was concluded that the access to technologies for demand-side flexibility tends to yield significant spillover effects on households' energy consumption behavior. The access to technologies for demand-side flexibility positively influences households' understanding of their energy consumption, facilitates the saving of energy costs, and is associated with further considerations to adopt additional technologies for demand-side flexibility and digital technologies in general. The results also indicated that the adoption of technologies for demand-side flexibility contributes to increased openness for technological automation as well as comfort and control for household members.

Interpreting these spillover effects in reverse enabled the identification of potential injustices which might influence the participation of households at risk of energy poverty in the energy transition in the long term. For households at risk of energy poverty with limited access to such technologies, this might entail a decreased ability to gain insights into their energy consumption patterns, potentially resulting in less opportunities to save energy costs. Their limited access might lead to decreased comfort for household members and an increased reluctance to adopt technologies for demand-side flexibility and digital technologies in general. In the longer term, this is associated with the fundamental injustice that households at risk of energy poverty might bypass the energy transition altogether.

Under incorporation of the results from the two sub-research questions, the main research question was targeted at the identification of injustices associated with the current access of households at risk of energy poverty to technologies for demand-side flexibility. The injustices were structured along the energy justice principles of affordability, availability, transparency and accountability, sustainability and intragenerational equity which were addressed together, intergenerational equity, responsibility, as well as the three added principles of comfort, the Resource Man, and the social license to automate. These principles were derived on the basis of the energy justice framework by SOVACOOL ET AL. (2016) whose flexible character not only facilitated the framing of each principle according to the research background, but it also gave room to expand and omit principles, ultimately resulting in the identification of twenty injustices. Eighteen of these injustices were structured along the ten energy justice principles. The remaining two injustices were not directly allocated to a principle. Instead, the first one, identified through the first sub-research question, serves as a prelude for the identification of further injustices. The final injustice, derived from the results of the second sub-research question, acts as a summary for the previous injustices as it alludes to the repercussions associated with the limited access to technologies for demand-side flexibility and the participation of households at risk of energy poverty in the energy transition in the long term.

The identification of potential solutions to tackle energy injustices through practice-oriented solutions prompts a discussion about the relevance of the obtained results as well as their transferability to other contexts. The research findings are particularly relevant to address the social implications of the energy transition. It was illustrated that energy poverty represents a structural and still rather overlooked problem of which certain households in Germany are more affected than others. In this context, the introduction of technologies for demand-side flexibility is associated with opportunities, but also risks. Hereby, the findings illustrated that the decisions taken by stakeholders such as the government, the private sector, but also landlords and landladies might yield unanticipated results which bear the risk of putting disparate burdens on parts of society. As such, it sensitizes decision makers to consider the outcomes of choices made in the context of the energy transition which might differ significantly among social groups. Furthermore, the research sheds light on the injustices which resulted from decisions around the German *Energiewende* in the past and might result from it in the future. Thereby, it paved the way for the identification of solutions to alleviate injustices and ensure social inclusion throughout the energy transition. Since demand-side flexibility on the household level is a gradually developing, albeit already significant, topic within the German energy transition, the obtained results can thus be equally used for reflections on past decisions while also serving to influence future policies in the realm of the *Energiewende*.

Apart from the previously outlined practical relevance, the research contributed to the academic discourse at the intersection of energy justice, digital technologies, and energy poverty. The paper outlined central characteristics which influence households' risk of energy poverty, acknowledging that the limited contribution to demand-side flexibility might further exacerbate said risk. Thereby, it enhanced the scarce literature on energy poverty in the German context. The research significantly drew on the research gap on energy poverty and demand-side flexibility from an energy justice perspective in the academic literature. Correspondingly, the findings significantly widened the discourse around energy injustices associated with households at risk of energy poverty by drawing attention to the structural obstacles with which they are confronted in the realm of technologies for demand-side flexibility. Moreover, the identified spillover effects yielded fundamental, previously underexplored insights into potential long-term effects associated with the access of households to technologies for demand-side flexibility on the energy transition. It was thus concluded that the three research questions were holistically answered and the research goal was met.

8.2 Beyond the German *Energiewende*

A critical deliberation on the transferability and generalizability of the research findings necessitates a brief reflection on the German energy transition. The studied case is characterized by the federal structure in which states and municipalities significantly shape the decisions around the energy transition. Supranational organizations, particularly the European Union, represent a further influence on the *Energiewende*. The German energy transition is, furthermore, comparatively far advanced. This illustrates that countries' energy transitions might significantly differ among countries as their development is influenced by a plethora of factors. Yet, this does not imply that the research findings are merely applicable for Germany. Rather, the careful consideration of country-specific peculiarities, among them their political, economic, administrative, and cultural background, but also their climate and housing infrastructure, as well as the influence of supranational organizations enables, to an extent, the transfer of the obtained results to other countries.

Against this background, it is anticipated that the findings of the first sub-research question which shed light on characteristics of households at risk of energy poverty and their contribution to demand-side flexibility largely apply for other countries, as well. The same is expected for the second sub-research question targeted at the identification of spillover effects associated with the access to technologies for demand-side flexibility on households' energy consumption behavior. While certain injustices summarized under the main research question such as the one associated with the German smart meter rollout are case-specific, it is assumed that the majority of identified injustices can serve as a foundation to enable discussions around energy justice and demand-side flexibility in other countries, particularly European ones whose energy transition has advanced to a similar degree as the German *Energiewende*.

8.3 Limitations and Further Avenues of Research

Lastly, an overview of the limitations associated with this research permits the identification of further avenues of scientific work. A central limitation of this research is the lack of direct insights from households at risk of energy poverty. It has been concluded that reaching this demographic is accompanied by central barriers, ranging from busy lifestyles, the comparatively infrequent use of social media platforms, particularly Facebook groups and Instagram pages, to people's hesitancy to share personal insights due to perceived bias in the realm of poverty. The perceptions from households at risk of energy poverty might have enriched the results of this paper substantially. Yet, instead of perceiving it as a mere limitation, it serves as an invitation for future researchers to directly address said households and expand the scientific discussion around energy poverty and demand-side flexibility. Suitable methodologies include, but are not limited to, semi-structured interviews, online surveys, and focus groups.

Furthermore, the identification of central characteristics which contribute to households' risk of energy poverty illustrates that certain groups of society are more at risk than others, for instance single parents, the elderly, or people with a migration background. With that, however, the potential scope of vulnerable social groups which should receive particular attention in the energy transition is not exhausted. This highlights two further areas of research. On the one hand, future researchers could focus on a particular social group at risk of energy poverty to assess whether the identified injustices apply. On the other hand, it might serve as a foundation to determine additional sections of society which were overlooked in this research but might be negatively affected by the expansion of technologies for demand-side flexibility. One such vulnerable group which remained fully unconsidered are chronically ill people whose perspective might enhance the scientific discourse around energy justice significantly.

Moreover, the results of the second sub-research question under consideration of the targeted social group yields room for further considerations. Addressing households who already possessed technologies for demand-side flexibility resulted in the identification of a particular demographic. Hence, despite acquiring 133 responses from participants all over Germany, the results are not representative. Due to this, it remains unclear to which extent the results are transferable among other groups of society. In other words, the survey does not grant insights into the degree to which these spillover effects are influenced by participants' tech-savvy character and positive approach towards digital technologies which might be assessed through further scientific studies. This also entails that the injustices associated with the current access of households at risk of energy poverty to technologies for demand-side flexibility consolidated under the main research question are not exhaustive. Rather, it is assumed that the results of the main research question do not encompass all injustices households at risk of energy poverty face in this context. Thus, future researchers are encouraged to examine the research topic further, for instance through an adjusted methodology or in a different context.

An additional consideration in this nexus which could be the focus of an entire study is whether the solutions which were recommended in the previous chapter to address the injustices might result in further injustices itself. As SOVACOOL ET AL. (2017) acknowledge, "[s]ometimes or perhaps even often, energy justice issues do not exist in black or white – there is no single, or even identifiable, immediate "winner"[,] nor an immediate, discernable "loser"[.] Instead, there are bundles or constellations of winners and losers, and even "pro-justice" interventions can create some type of inequality, even when they offer net societal benefits" (p. 684). This entails that potential solutions which were designed to address injustices potentially result in a trade-off; while they might solve an injustice for a certain part of society, they might deepen one for another. This calls for further practice-oriented research to fully comprehend these injustice trade-offs between solutions.

Finally, the findings should be understood against the energy transition by the time the research was conducted. The intersection of energy justice and demand-side flexibility was addressed while associated technologies and innovative tariffs were still gaining momentum in Germany. Thus, as illustrated through principles such as intergenerational equity and the social license to automate, the research exhibited a central future component. Amidst the increasing establishment of technologies for demand-side flexibility as well as the corresponding tariffs among German households, the research findings could be revisited and validated. This should encourage researchers to frequently address emerging justice considerations against the progressing energy transition.

Throughout this paper, the perspective of energy justice was applied to assess whether technologies for demand-side flexibility constitute to a just energy transition for every household in Germany alike. As such, energy justice scholarship surpasses beyond the mere technical sphere of the energy transition. While acknowledging that technologies for demand-side flexibility contribute to overall system balance, it challenges whether this ultimately suffices to ensure equality. By focusing on sections of the society who might be negatively affected by the energy transition, energy justice appeals for a multi-faceted, critical investigation of phenomena by which this trajectory is accompanied, such as technologies for demand-side flexibility. The latter potentially confronts households with benefits but also burdens previously unknown. As households' ability to participate in the increasingly digitalized energy transition is determined by their access to technologies for demand-side flexibility, this paper invites decision makers to incorporate notions of energy justice into the design and implementation of policies, digital technologies, and energy tariffs.

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