WIRTSCHAFTSUNIVERSITÄT WIEN
Vienna University of Economics and Business

Bachelor Thesis

Title of Bachelor Thesis (english)	Understanding User Requirements: Exploring the Significance of Explainability in Smart Energy Systems
Title of Bachelor Thesis (german)	Verstehen von Nutzeranforderungen: Untersuchung der Bedeutung von Erklärbarkeit in intelligenten Energiesystemen
Author (last name, first name):	Kordulova, Lada
Student ID number:	11913739
Degree program:	Bachelor of Science(WU), Bsc (WU)
Examiner (degree, first name, last name):	Dipl.-Ing. Katrin Schreiberhuber, B.Sc. Prof. Dr. Marta Sabou

I hereby declare that:

1. I have written this Bachelor thesis myself, independently and without the aid of unfair or unauthorized resources. Whenever content has been taken directly or indirectly from other sources, this has been indicated and the source referenced.

2. This Bachelor Thesis has not been previously presented as an examination paper in this or any other form in Austria or abroad.

3. This Bachelor Thesis is identical with the thesis assessed by the examiner.

4. (only applicable if the thesis was written by more than one author): this Bachelor thesis was written together with

   The individual contributions of each writer as well as the co-written passages have been indicated.

26.07.2024 — L. Kordulová

Date — Unterschrift

WIRTSCHAFTS
UNIVERSITÄT
WIEN VIENNA
UNIVERSITY OF
ECONOMICS
AND BUSINESS

EFMD
EQUIS
ACCREDITED

Bachelor Thesis

Understanding User Requirements: Exploring the Significance of Explainability in Smart Energy Systems

Lada Kordulova

Date of Birth: 24.09.2000
Student ID: 11913739

Subject Area: Information Business

Studienkennzahl: 033 561

Supervisors: Katrin Schreiberhuber, Marta Sabou

Date of Submission: 26.July 2024

Department of Information Systems & Operations Management, Vienna University of Economics and Business, Welthandelsplatz 1, 1020 Vienna, Austria

DEPARTMENT FÜR WIRTSCHAFTSINFORMATIK
UND OPERATIONS MANAGEMENT DEPARTMENT
OF INFORMATION SYSTEMS AND OPERATIONS
MANAGEMENT

Contents

Abstract

This thesis explores the world of smart energy systems, with a specific focus on understanding the importance of explainability in meeting user needs. As smart energy technologies evolve, they offer promising avenues for energy management. However, the success of these advancements relies on putting users first, prioritizing their engagement, satisfaction, and trust. The research design of this study tackles a gap in the understanding of explainability within smart energy systems. By investigating how users perceive transparency, explanations, and their impact on trust and acceptance of these systems, the study uncovers what end users truly need and expect. Through a thorough examination of survey results posed to the Renewable Energy Communities in Austria, the study reveals valuable insights into the essential role of explainability. It shows how clear explanations from intelligent energy systems are vital for fostering user trust, ensuring system transparency, and enhancing user engagement. The findings emphasize the importance of personalized communication and transparent interfaces in building trust and satisfaction with smart energy systems. This research advocates for an ongoing focus on user-centric design principles that prioritize clear, understandable, and personalized communication. By bridging the gap between technology and user accessibility, the study underscores the critical role of explainability in enhancing user trust, satisfaction, and system usability.

1 Introduction

Smart Energy Systems - an innovative framework resulting from the need to coordinate energy production, distribution, and consumption - has drawn the interest of pioneers who seek to bring enhanced efficiency, reliability, and sustainability into the energy sector [1]. Claessen and La Poutre describe smart energy systems as resulting from the combination of advances in digital technology with the growing adoption of renewable energy sources [2]. They argue for the strong need for sustainable energy solutions, and the ability of information and communications technology to manage the varying nature of energy sources. This need has impelled governments, industries, and researchers to incorporate smart energy systems as a key part of an initiative designed to the way we consume and conserve energy [2]. Smart energy systems transformation is described as a complex process influenced by technological innovation, regulatory frameworks, market forces, and social values, all of which shape the energy system of today and tomorrow [2]. The journey of discovery to such integrated systems is not only a technological crossing, but a socioeconomic shift, that researchers attempt to collectively understand as they anticipate the future [3].

The journey to weave together a cohesive Smart Energy System is made even more challenging by the variety of stakeholders involved, each of them holding their unique ambitions and needs. O'Dwyer and colleagues emphasize the critical role of advanced computational resources and extensive sensor networks in navigating the technical complexities engrained in these systems. Systems must harmonize the objectives of various participants over different scales and timeframes. In their study, O'Dwyer and colleagues also shed light on recent progress, highlighting the role of embedded computational intelligence in navigating these challenges . They argue for the development of resilient and flexible energy networks, designed to meet the dynamic requirements of users [4].

However, as these systems gain intelligence and autonomy, the importance of maintaining clarity and comprehensibility for the user comes to the forefront. The emerging field of explainability in systems, as explored by researchers focusing on recommendations for energy conservation, highlights the need for smart energy systems to be not only technically adept but also accessible and usable for non-experts [5]. This need for explainable smart energy systems is driven by the understanding that their widespread acceptance and trust are critical to their success.

Furthermore, understanding user requirements has become essential in the design and implementation of interactive systems, therefore also Smart Energy Systems, as described by Maguire and Bevan [6]. Recognizing user needs is important for ensuring that smart energy systems are not just efficient and sustainable but also user-friendly and customized to the specific contexts in which they operate, as the impact of Smart Energy System technologies on energy demand is deeply rooted in social variables such as personal preferences, household dynamics, and daily routines [6] [7]. Therefore, the development of smart energy systems should be approached from the user-centric perspective, with a focus on ensuring that technological advancements are accompanied by an increase in user engagement and satisfaction.

In this scenario, the combination of digital innovations with sustainable energy sources paves the way for new ideas. However, the success of these innovations depends on commitment to a user-focused strategy. It is here that the concept of explainability becomes critical, serving as a link between the complex system operations and user understanding. The integration of user requirements into the development of smart energy systems holds the promise of not only enhancing the performance of these systems but also creating an environment of trust and cooperation between technology providers and communities.

2 Research Design

Despite the already acknowledged importance of explainability in a broader context, there is still a lot to be explored regarding this topic. Specifically, the relevance of explainability within the domain of Smart Energy Systems continues to be a relatively unexplored area. This research gap points out the need to clarify how explainability can shape the interaction between end users and smart energy systems. It raises questions as to which extent users desire transparency, view explanations as a tool to achieve this, and how these factors influence their trust and acceptance of these systems. This research aims to close this knowledge gap, by looking at the specific needs and expectations of end users interacting with smart energy systems. By focusing on the significance of explainability for end users within the context of smart energy systems, this research also aims to uncover how these systems can improve the way they communicate energy management decisions.

To gain insight into the user experience from the end-user perspective, a survey was conducted. The decision to use surveys as the primary research method is rooted in the objectives of this study, which delves into the relatively unexplored realm of explainability and user requirements within smart energy systems. Several factors support the suitability of surveys in this context. Firstly, the many topics surrounded by smart energy systems demand a method that can accommodate multifaceted inquiries. Surveys provide a framework for asking diverse questions, allowing the exploration of multiple topics. Another reason for conducting as survey is their versatility, as it allows the investigation of interconnected themes within a single study, thereby providing a thorough understanding of the research domain. Furthermore, the focus of study is understanding user requirements and the end-user perspective. Surveys offer a direct means of exploring this aspect, providing valuable insights into what end-users truly need and expect from smart energy systems. By employing the strengths of survey methodology, the study aims to provide a comprehensive exploration of the specific needs, expectations, and perceptions of end-users within Austrian Energy Communities. Lastly, the efficiency of surveys makes them particularly well-suited for investigating topics high societal relevance within a reasonable timeframe. In a rapidly evolving field like smart energy systems, where technological advancements and user preferences continually evolve, the timeliness of data collection and analysis is important. Surveys are time-efficient in gathering insights, helping to stay informed about the latest trends and developments as they unfold.

To be answered in this research are the following research questions:

RQ1: What are the specific needs and expectations of the end users when interacting with smart energy systems in real-world scenarios?

RQ2: To what extent does the explainability of smart energy systems influence end user trust and acceptance?

RQ3: How can smart energy systems effectively communicate explanations about energy management decisions to end users?

3 Related Work

This section consists of a literature review relevant to the topic of explainability within smart energy systems. Its purpose is to establish a theoretical framework for the following analysis. The exploration contains the topics of smart energy system fundamentals, their benefits and challenges, the concept of explainability, and user requirements, which are crucial for building a solid foundation of knowledge before delving into the survey analysis. The theoretical framework sets the stage for a better grasp of the survey data and provides essential context and definitions to interpret the survey findings more effectively.

3.1 Smart Energy Systems

Smart energy systems have emerged from a shift from traditional energy networks and single-sector thinking, towards more integrated, efficient, and sustainable models of energy use [8]. A formal definition of smart energy systems, which has established itself throughout the research, contains the adaptation of technologies and infrastructures, that introduce new forms of flexibility, especially in the conversion stage of the system, which involves the utilization of different technologies and processes to convert renewable energy sources into energy that can be efficiently distributed [8] [9] [10]. The underlying architecture of this smart energy system is a network of smart grids: electricity grids that use intelligent technologies to balance demands (such as electric cars) with renewable energy resources, thermal grids that tie together heating and electricity sectors to harness and recycle thermal energy, and gas grids that connect heating, electricity, and transport sectors [9] [10]. But these systems are characterized by more than just their infrastructures, they're about creating synergies among them. Therefore, Smart energy systems can be defined as networks of intelligent electricity, heating, and gas frameworks, connected with storage capabilities and managed in a way that maximizes efficiency for each sector, as well as the energy system [8].

Smart energy systems are characterized by the integration of modern technologies such as artificial intelligence (AI), leading their development being more responsive, efficient, and intelligent [11]. Critical technologies like smart calculation and measurement methods [12] or intelligent control [13] support distributed decision-making and collaborative autonomy, while also increasing security within the smart energy system framework [14]. Some researchers even argue that AI technology has not only digitalized the energy industry, but also contributed significantly to the emergence of smart energy systems [14].

Another recognition which must be considered, is that the emergence of smart energy systems isn't just a technological advancement, but also a societal transformation. In the work of Zaidan et al., it is emphasized that the transformation of urban communities into smart-energy communities calls for a blending of social, technological, and economic factors, while utilizing the local and regional traits to establish a future of energy efficiency[3]. This movement towards more smart energy communities is highlighted in studies related to smart energy systems within smart city frameworks, which also further point out the essential role of computational intelligence [3][4]. Here, the significance of information and communication technology is underscored as critical for creating a structural and sustainable shift in energy systems [4]. Moreover, from a European perspective, smart energy systems are seen as integral to achieving the EU's goals concerning energy security, competitive markets, and sustainable energy pracrices[2]. This vision acknowledges not just the regulatory frameworks, but also the dynamics among stakeholders, and the technological progress [2].

3.2 User Benefits and Potential Issues of Smart Energy Systems

One of the key elements of any smart energy system is the end user [15]. Addressing future energy challenges requires more than just new technologies and system changes, the involvement of consumers is essential. They're not just end-users of energy. Their actions, choices, and willingness to adopt new technologies greatly impact how effective and sustainable our energy systems can be [15]. This view makes it clear that the success of energy systems in the future - balancing what we need, what's available, and our environmental goals - depends not only on new technologies but also heavily on how people behave and accept these changes. It underlines the necessity of a collective engagement to enhance the efficiency, adaptability, and environmental sustainability of our energy consumption.

Smart energy systems display a wide set of advantages that are in direct correlation with the requirements of consumers. To begin with, smart energy systems contribute to significant cost savings by promoting local energy consumption and conservation [15]. Additionally, they elevate consumer consciousness and enable the use of valuable data through advanced technologies, including smart meters and home automation, which provide access to insights that were once beyond the reach of consumers, as detailed in sources [16] and [17]. Additionally, smart energy systems empower consumers to actively engage in the energy market, making use of real-time pricing and collective energy strategies to adjust their energy usage efficiently [15]. Lastly, they take consumer preferences into account, achieving energy utilization that is not only efficient but also customized to meet individual preferences, as shown in reference [18]. Through all of these innovative measures, smart energy systems are able to meet specific consumer needs while presenting flexible solutions that elevate the value of services and products.

With this number of benefits, smart energy systems represent a key step towards sustainable and efficient energy management. However, this path is not devoid of challenges in the areas of technology, economics, and operations. For example, incorporating solar power, an important source of renewable energy, highlights the economic issue of high initial costs [19]. This reflects broader difficulties in expanding and scaling up smart energy systems. Moreover, the complexity of smart energy systems, due to their reliance on advanced data analytics for management and optimization, raises a significant challenge: making these systems "explainable" [19] [20]. This is crucial because it impacts how transparent and accountable smart energy system operations are, as well as how much they are trusted and accepted by people involved. To fully benefit from smart energy technologies in achieving our sustainable energy goals, it's vital to address these challenges head-on, making sure the algorithms that smart energy systems use are clear and their decisions can be easily explained [19].

3.3 Explainability

Explainability in the context of software-intensive systems, has emerged as a key quality attribute, essential for creating user trust and ensuring that the system is transparent [21]. As systems become more intelligent, their complexity also increases, creating a challenge for both users and developers to comprehend how exactly they work and the rationale behind their decisions [21]. This complexity, which is particularly evident in artificial intelligence within smart city infrastructures, has increased the need for systems to be more interpretable and transparent [22].

The recent advancements of artificial intelligence, marked by machine learning and deep learning techniques, have notably improved the capabilities of intelligent systems. However, this has also led to the creation of complex models that operate as "black boxes," where the decision-making process is difficult to understand [22]. This opacity is a significant concern, as it can impact the trust users place in these systems, which is critical for their acceptance and satisfaction [21].

'Explainable artificial intelligence' seeks to address these concerns by making AI's decisions understandable to humans, therefore bridging the gap between AI's complexity and human comprehension [22]. It tries to address the opacity of artificial intelligence systems, providing tools and techniques for making AI decisions transparent, understandable, and ethically sound by clarifying the internal logic of these "black-box" algorithms [23]. By ensuring that AI systems can provide clear and understandable explanations for their actions, explainable artificial intelligence creates a sense of trust and clarity between their technologies and users [21]. Studies therefore indicate that by addressing the opaque "black box" aspect of software systems, explainability significantly boosts their perceived trustworthiness, transparency, accountability, fairness, ethics, and additional quality metrics [24].This approach is crucial for a broader acceptance and integration of AI technologies into society, especially in settings as integral as smart cities [22].

The recent advancements in machine learning and deep learning have not only heightened the performance of intelligent systems but have also raised human expectations for a deeper understanding of how these systems make decisions [5]. This is especially important in the context of recommendation systems, which play a central role in supporting human decision-making [5], especially regarding energy efficiency within smart cities. For systems like these to effectively increase user trust and to improve the acceptance of their recommendations, they must be designed with explainability in mind [5]. Sardinanos et al. emphasize the development of explainable and persuasive recommendation mechanisms that are personalized to user preferences and habits, leading to intelligent recommendations that promote energy-saving behavior [5]. This highlights the importance of explainability in enhancing the persuasiveness of recommendations, thereby creating a more profound trust in AI by providing users with clear, understandable reasons for each recommended action [5].

Furthermore, the lack of transparency and control in AI systems has undermined stakeholder trust, leading to an impact on the rate at which AI is embraced in the energy field [25]. In addition, the growing complexity in the design and operational aspects of energy systems, which include numerous variables and require coordination among various stakeholders, is escalating [25]. This increase in complexity, paired with risks associated with the critical nature of energy infrastructure to societal, national and environmental stability, underscores the need for more transparent and manageable AI systems [25].

3.4 User Requirements

User requirements express the functions, constraints, or properties that a system must possess to fulfill the needs of its users [26]. These requirements originate directly from the users or stakeholders, emphasizing the anticipated benefits or transformations that a new system is expected to introduce to a specific field [27]. User requirements focus on what users expect or want to accomplish with the system, rather than detailing how the system will achieve these tasks [27].

Understanding and accurately capturing user requirements is important for the design and success of interactive systems[6]. It ensures that the development of software-intensive systems is in direct alignment with the actual needs and expectations of end-users, thereby enhancing the usability and acceptance of these systems [6] [28]. However, it is essential to differentiate between user requirements and system requirements, as confusing them can lead to complications in project development. User requirements are about the desired changes or capabilities from the user's perspective, while system requirements detail the specific features or functions the system must have to satisfy user requirements [27].

The process of identifying and analyzing user requirements is a fundamental aspect of user-centered design, focused on ensuring that new systems meet the users' needs and facilitate their goals in an effective, efficient, and satisfying manner [26]. As the demand for systems to be more transparent and understandable increases the importance of clear and well-defined user requirements becomes even more pronounced [27].

4 Research Method

To look at the needs of end-users who interact with smart energy systems, a methodical approach is key. The focus is on non-technical end-users, the main audience for these systems. Therefore, a survey was conducted among members of the Renewable Energy Communities in Austria, the renewable energy communities in particular, to gather insights into real-world scenarios and the role of explainability and user requirements. The process of designing the survey was motivated by the overarching goal of gaining a thorough understanding of user needs and viewpoints within the Renewable Energy Communities. It started with an in-depth exploration of existing literature and theoretical frameworks within the topic smart energy systems, explainability, and user requirements. This initial phase provided a solid foundation for understanding the essential concepts shaping user interactions with smart energy systems. As the phrasing of the survey questions commenced, it was important to assess their general thoughts on these systems. Following this, attention shifted towards exploring users' existing expectations and requirements regarding explainability. Finally, direct questions about explainability were included to delve deeper into this aspect. Special attention was paid to language clarity, question structure, and response options to resonate with participants from diverse backgrounds and technical proficiency levels. To capture the multifaceted nature of user experiences and attitudes, the questionnaire employed a mixed-methods approach, incorporating closed-ended Likert-scale items for quantitative analysis and open-ended prompts for qualitative insights. Lastly, pilot testing was conducted to ensure the reliability and validity of the survey instrument.

4.1 Survey Design

The structure of the survey for this research is designed in a way to investigate the dynamics between end users and smart energy systems. The survey, which was designed in 'Google Forms' is divided into key sections, each serving a purpose in unraveling the relationship users have with smart energy systems.

4.1.1 Survey Introduction

Firstly, the survey sets the stage by introducing the participants to the concept of smart energy systems and providing a real-world scenario, ensuring a shared understanding of smart energy systems. This part is essential for enabling more precise and informed responses throughout the questionnaire.

The introduction explains the basics of smart energy systems to the survey participants, who might not be familiar with this concept. The introduction emphasizes the role of smart energy systems in intelligently managing energy users and producers to achieve optimal outcomes. It describes how these systems automate decisions like scheduling electric vehicle charges, enhance grid stability, and offer cost-effective solutions for users. This section also highlights some of the benefits of smart energy systems, such as reduced electricity costs for energy community members and improved grid stability for operators.

The important concept introduced here is 'explainability,' which refers to the system's ability to clarify its decision-making processes. An example involving a smart thermostat illustrates that when it unexpectedly raises the temperature, leading to higher costs, a clear explanation from the system can help users understand the reason behind this decision and make the necessary adjustments. Furthermore, the introduction also contains a link to the English version of the survey for non-German speakers.

4.1.2 User Experiences and Needs

The following section, about user experiences and needs, explores the users direct interactions with smart energy systems and their thoughts about them. This part is designed to uncover the motivations for the adoption of smart energy systems and to identify the benefits users seek from integrating these systems into their daily lives. The intention behind these questions is to pinpoint the key factors that influence user decisions and satisfaction with smart energy systems.

The questions in this section start by asking participants whether they have any smart energy systems in their homes or communities. Examples provided include energy management systems, smart thermostats, and electric vehicle charging stations with charge management. This helps grasp the understanding of the participants' familiarity and experience with such technologies. The following question delves into the primary motivations for using smart energy systems. Participants select up to three of their main reasons from a list that includes options such as optimizing energy consumption, making informed decisions about energy use, reducing energy costs, improving energy efficiency, and engaging in proactive energy management based on real-time data. There is also an option for participants to provide their own motivations if they are not listed.

4.1.3 Challenges to Smart Energy Systems

Following this, the survey also considers challenges and limitations associated with smart energy systems. By inspecting the main difficulties the respondents encounter, this section's objective is to analyze the barriers that might hinder the broader acceptance and utilization of smart energy systems. Understanding these challenges is essential for identifying areas where smart energy systems could be improved to better meet user needs and enhance system usability.

Participants are asked to select the most important challenges or limitations they face or might face when using smart energy systems. They can once again select a maximum of three choices, which they can pick from a list of potential challenges such as difficulties in understanding the system's recommendations or behavior, lack of clarity on how the system impacts their energy consumption, concerns about data privacy and security, technical difficulties or malfunctions, and limited integration with other smart home devices. There is also an option for participants to specify other challenges they might be experiencing which are not included in the selection.

4.1.4 Importance of Clear Information and Customization

The next few questions, which also belong to the 'User Experiences and Needs' part of the survey, focus on understanding the value users place on clear communication regarding energy management decisions and the importance of system customization to individual needs. This part includes several Likert-scale questions using a scale from 1 (not at all) to 5 (very much) to understand these aspects. One question asks to what extent participants value clear information about energy management decisions, another question assesses the degree to which users believe smart energy systems should be customized to individual needs. The next question asks the participants about the importance of clear communication of the functionalities of energy management tools to meet user expectations. Finally, the survey explores how users' belief in understanding a smart energy system impacts their trust in the technology. These questions aim to reveal how important clear communication and customization are for user satisfaction and trust in smart energy systems.

4.1.5 Explainability Preferences and Expectations

Central to the survey is the exploration of preferences and expectations regarding explainability. This part of the survey focuses on determining the value users place on the transparency of decision-making processes of smart energy systems. It seeks to understand the preferred formats for receiving explanations and how explainability influences trust and acceptance of smart energy systems. The questions within this section are chosen to assess the importance of clear communication and the role it plays in user engagement with smart energy systems.

At the beginning of this section, participants are directly asked about the importance of explainability itself, rating how essential they find it for smart energy systems to explain their decisions. This question aims to directly assess the value users place on having transparent and understandable systems. To identify specific benefits or important aspects of explainability, participants choose from options such as understanding how the system works, increasing trust and acceptance, identifying potential problems, tailoring the system's behavior to user needs, and gaining insights into energy consumption patterns. They can select up to three options they consider most significant, which helps prioritize the various aspects of explainability from a user perspective. The following question asks participants to rank factors that influence their trust and acceptance of explanations. They rank answers such as clarity and conciseness, tailoring to individual needs, providing insights into the system's reasoning, and consistency with their personal understanding of energy management. This ranking helps identify which factors are most important to users in accepting and trusting the explanations provided by smart energy systems. Finally, the survey also explores the preferred formats for receiving explanations. Participants can select their preferred formats from options like interactive chatbots, text-based explanations, visual explanations (e.g., graphs, charts, dashboards), interactive visualizations, and combinations of these formats. There is also an option for participants to suggest other preferred formats, ensuring the survey captures a wide range of user preferences.

4.1.6 Demographic Information

Lastly, the survey finishes with demographic questions, to gather comprehensive data from a broad spectrum of respondents. Systematically collecting demographic information contributes to a comprehensive understanding of the survey's reach.

Participants are asked to assess their technical knowledge in the area of energy management, choosing from options like no technical knowledge, basic understanding of energy concepts, and higher level of technical expertise. Other demographic questions cover age, gender, duration of membership in an energy community, and the population density of their living area. These questions help categorize the respondents and provide insights into how demographic factors might influence user experiences and preferences regarding smart energy systems. The demographic section also includes optional questions for participants who wish to further support the research or receive survey results. Participants are asked if they are interested in supporting the research with their technical expertise or if they want to be informed about the survey results, and they can leave their email addresses for this purpose. Additionally, there is a space for any further comments they might have.

Overall, the survey design addresses the aspects of user interactions with smart energy systems, focusing on experiences, challenges, and preferences for system explainability. This approach ensures that the survey data will provide valuable insights into enhancing user engagement and satisfaction with smart energy technologies.

5 Data Collection

Following the research methodology that was previously outlined, the survey was developed to gain insights into user interactions and expectations regarding smart energy systems and their view on explainability in smart energy systems. This exploration was built on the idea that the performance and success of interactive systems deeply depend on the understanding of user needs [6]. As pointed out by Maguire and Bevan, the key of developing information systems lies in the identification and integration of user requirements [6]. This aspect is also of importance in the context of smart energy systems, where the level of user engagement and satisfaction directly influence the practicality and effectiveness of the system [15]. Recognizing the challenges in understanding user expectations, especially when the users themselves might not know their future needs for the system, this survey aims to narrow the gap between user aspirations and system capabilities.

The survey, titled 'Smart Energy Systems: A Survey on Explainability', targets members of Austrian Energy Communities, the Renewable Energy Communities in particular. Its purpose is explore their deeper perspectives about how transparent and understandable smart energy systems are, as well as their expectations and requirements about smart energy systems. The focus is on explainability, which is crucial for generating a level of trust and satisfaction among users [29]. By concentrating on the Austrian energy communities, the survey intentionally taps into a demographic that is relevant to the discourse on smart energy systems.

By engaging with participants who are likely to be familiar with these systems, the survey is set to uncover valuable insights. This proactive engagement with end-users supports a methodological approach that emphasizes the integration of user feedback into the development process. Focusing on the user-centric perspective guarantees that improvements are directly shaped by actual user needs and experiences, leading to solutions that are not only more effective but also highly relevant to those they aim to serve.

Participants for the survey were recruited from a network of renewable energy communities. As of January 2024 a publicly available list contained 317 energy communities, which also provided the contact information for their respective spokespersons, who were then individually approached [1]. The process involved reaching out directly to these spokespeople, asking for their participation and their collaboration in sharing the survey to their community members. Due to the fact that some communities shared a spokesperson, only a single contact approach was followed through, to ensure efficiency. The distribution of the survey was conducted through direct emails. This method was chosen for its potential for higher engagement. The email to each spokesperson included an explanation of the survey's purpose and importance, instructions for participating, and a link to the survey. The spokespersons were then asked to forward this information to their community members, to open the survey's reach to a broader audience.

During the data collection phase, some challenges were encountered, for instance a lower than anticipated response rate. This was in part due to the nature of some energy communities, such as nonprofit energy communities, which faced certain limitations that ruled out their participation. Additionally, a few communities were unable to participate due to an existing high volume of requests and engagements. To address the challenge of low response rates, a two-part strategy was implemented. Firstly, communities unable to contribute were not approached again, acknowledging their organizational limits and existing obligations. Secondly, a follow-up email to the remaining communities was dispatched about two weeks after the initial request. The purpose of this reminder was to re-engage potential respondents and provided an additional opportunity for those who might have missed or overlooked the initial invitation to contribute to the study. This method proved effective in lifting response rates and ensuring a broader dataset for analysis.

After the follow-up reminders were sent and a sufficient response window had

[1] Link for the list of the Austrian Energy Communities: `https://energiegemeinschaften.gv.at/landkarte/`

passed, the survey was closed approximately one and a half months after its initiation. This time period allowed for an adequate response time, ensuring a robust participation rate. Upon closing the survey, the process of data preparation was started. This included a thorough review of the final 49 collected responses and the organization of the data to enable a comprehensive and methodical analysis. This preparatory stage is critical as it lays the groundwork for a deep analysis and the drawing of significant insights from the survey findings.

6 Data Analysis and Results

The following chapter takes a closer look at user interactions with smart energy systems, particularly within the Renewable Energy Communities, in an attempt to address the concerns associated with the adoption and acceptance of these systems and what role user requirements have in this context. It forms the key basis of this research, which is to analyze the role of explainability in smart energy systems from an end-user perspective. Given this, the research captured insights through the survey into the user's experiences, pinning their expectations and the challenges they face to the integration of smart energy systems. The analysis part of the research closely examines the user feedback to establish the main patterns and insights that respond to the essential questions this study intended to answer.

The findings shed light on real-world user needs and expectations that should be included in smart energy systems, the role of explainability in building user trust, and effective communication strategies for energy management decisions. The resulting discussion is an attempt to consider the gap that may still remain between system functionalities and user satisfaction, and to propose means to improve this in a way that resonates with the user's perspectives. This section also provides a foundation for recommendations, that are aimed at fostering sustainable interaction between end-users and the technology designed to optimally utilize their energy.

6.1 Initial Data Review

The data analysis phase of the research started with a review of the responses gathered through the survey. Following the data collection, the survey results were gathered and examined to ensure the readiness for an in-depth analysis. Using Google Forms for the survey implementation has the advantage of ensuring the completeness of responses. Since this platform supports the configuration of mandatory fields, respondents had to complete all required questions before they could submit their responses. This helps with the collection of complete response data without missing values, which is particularly valuable for research purposes. It ensures that every collected response is usable, and that the analysis can be reliable and comprehensive. The in-depth review started with an examination of the aggregated data provided by the survey platform. It conveniently offers a summary overview of all answers, which serves as the starting point of the analysis. By first looking at the general trends and frequencies in this summary, a broader understanding of the data is gained. This overview helps to identify first patterns and potential areas of interest. After looking at the collective data, the process moved to a comprehensive review of individual responses. For those questions with an open-ended 'other' response option, where participants could type in their answer which was not mentioned yet, all such entries have been taken as additional aspects or another view that the respondent had in mind. Those were important qualitative data, which provided more context and maybe another type of insight than predefined questions could offer. This option in a survey also allowed for greater flexibility by enabling respondents to express their true motivations, which then led to more accurate data and the discovery of unanticipated trends or behaviors. Each question's data was then arranged to reflect the frequency and percentage of each response, therefore indicating the collective viewpoints within the sample population. This approach was particularly useful for multiple-choice and ranking questions, as it simplified the visualization of the respondents' preferences and priorities. In addition to the response frequencies and percentages, the data analysis also included a look at the demographic information. This approach allowed a basic alignment of individual responses to demographic categories, providing an opportunity to consider possible trends or differences of opinion primarily across age, gender, and community size.

6.1.1 Quantitative and Qualitative Analysis

In analyzing the collected survey data, both qualitative and quantitative methods were employed, to fully capture user requirements and user's perceptions of explainability in smart energy systems. From a quantitative standpoint, numerous survey questions aimed to collect measurable data points. These were developed to measure the extent to which the smart energy system was integrated within their homes, including the levels of importance of explainability dimensions and the demographic spread of the respondents. The responses were summarized by the survey platform, and patterns were identified through the use of statistical techniques. This included looking at measures of central tendency, for example averages and most common responses, to determine the spread of responses across scale-based questions. Furthermore, the frequency with which various options were chosen in multiple-choice and ranking questions was analyzed, to establish which response categories were more popular amongst the survey respondents. The open-ended 'other' responses were analyzed with a qualitative perspective. In this sense thematic analysis was employed, allowing for the identification and examination of relevant themes in patterns that arise from qualitative data, looking at patterns or possible repetitions. The analytical techniques were selected based on the nature of the survey questions. Through quantitative analysis, the objective and clear general view of the numerical data was taken into consideration, which helps in assessing the preferences of people and majority sentiment in the surveyed population. This was complemented with qualitative analysis, inquiring further into the details of subjective experiences and views of users to give further depth to the understanding of the user requirements and perception of explainability. Integrating these approaches gives a comprehensive view of the responses, therefore also confirming that all aspects of the responses were taken into consideration in the development of conclusions and recommendations.

6.1.2 Demographic Contextualization

After examining the patterns in response frequencies and preferences, the analysis expanded to include demographic data, providing additional layers of context to the survey results. This step was important for understanding how different backgrounds and community settings might influence people's perception of smart energy systems. Analyzing the demographics in relation to the responses, provides a contextual background showing patterns and tendencies. From the 49 respondents, a significant majority were male (89.8%) while only 10.2% of the participants were female. This kind of gender distribution might suggest that among the sampled group, the engagement and feedback on smart energy systems were dominantly influenced by a male perspective. As for the length of membership in the energy community, the majority of the respondents (53.1%) have been a member for 1 to 3 years, which points to people having some kind of experience or knowledge about smart energy systems and the impacts brought by smart energy in society. This level of experience could bias both their expectations concerning the feedback from the system functionality, and bias the ability of the implementers to make informed feedback regarding system functionality and user requirements. Regarding the length of membership in energy communities, most respondents (53.1%) have been members for 1-3 years. This indicates a level of engagement and suggests a certain depth of understanding about energy systems and their impact within communities. Users' level of experience can affect their expectations and their ability to provide informed feedback on system functionality and user requirements. This was further supported by the perception the participants had of themselves concerning technical knowledge, with a majority (51%) indicating they have high technical expertise in energy management, and a further 38.8% claiming a foundational understanding of energy concepts. This demonstrates that most participants have at least some level of knowledge in this area, enriching the survey with a spectrum of insights into energy management. The study considered the size of the settlements where the participants lived. Most participants (61.2%) lived in small communities with under 5,000 inhabitants, while the next largest group lived in small towns, accounting for 26.5%. This distribution profile may suggest that the benefits of smart energy systems to user needs and community size could be different. These differences might be due to variations in energy infrastructure, community involvement, or individual energy consumption habits.

6.2 Key Findings and Recommendations

The survey results, derived from the responses of 49 people, enlighten the current landscape of Smart Energy Systems and how explainability is key to further user engagement and trust. Notably, 69.4% of the respondents report already having smart energy systems integrated into their homes or community settings, a finding that aligns well with the nature of renewable energy communities. This finding not only demonstrates the practical sense of adopting smart energy systems in such progressive environments, but also points to a broader trend towards adopting smart energy solutions. In addition, the trend observed among the respondents reflects a wider societal movement towards sustainable energy practices, where optimizing the use of energy for both environmental and economic benefits is becoming more and more important. This key finding leads to a more in-depth exploration of user motivations, personalized feedback, and the critical role of explainability in the following subsections.

6.2.1 Motivations for Adopting Smart Energy Systems

When looking into the reasons for adopting smart energy systems, an interplay of driving factors becomes visible. It is important to note that most of the motivations for adopting these systems are somehow interconnected and contribute to the overall benefits of the technology. That said, the primary reason for the deployment of smart energy systems, as cited by 79.6% of respondents, is the reduction of energy costs. This provides the basis for the practical and, at the same time, immediate benefit of using smart energy systems as a tool to save money. Additionally, 69.4% of respondents identified the optimization of energy consumption as one of the leading motivations. Therefore, they aim to use energy more efficiently, reflecting a collective acknowledgement of the importance of resource conservation and sustainability. The survey also surfaced other, relevant reasons than just costs and optimization that could drive the adoption of smart energy systems, such as efficiency in energy, stated by 42.9% of the respondents, and management by proactive energy with real-time data, also stated by 42.9%. These motivations reflect the understanding and appreciation of smart energy systems' capability in realizing both direct economic savings avenues and long-term sustainability and efficiency in using the energy resource. The survey also revealed that 20.4% of respondents value informed decision-making regarding their energy usage as one of the primary benefits, showing a desire for deeper understanding and control over energy practices. It is worth mentioning that only 8.2% of respondents cited personalized energy management as a main reason for implementing smart energy systems, meaning that despite these systems offering customization potential, this feature has not yet strongly resonated with most users. The lower percentage might mean that while personalization is recognized as beneficial, it may not be as immediately compelling or easily understood as more straightforward benefits such as cost savings and energy optimization. It might also reflect a current focus on general improvements that smart energy systems can provide before considering the more individualized advantages that come with personalization.

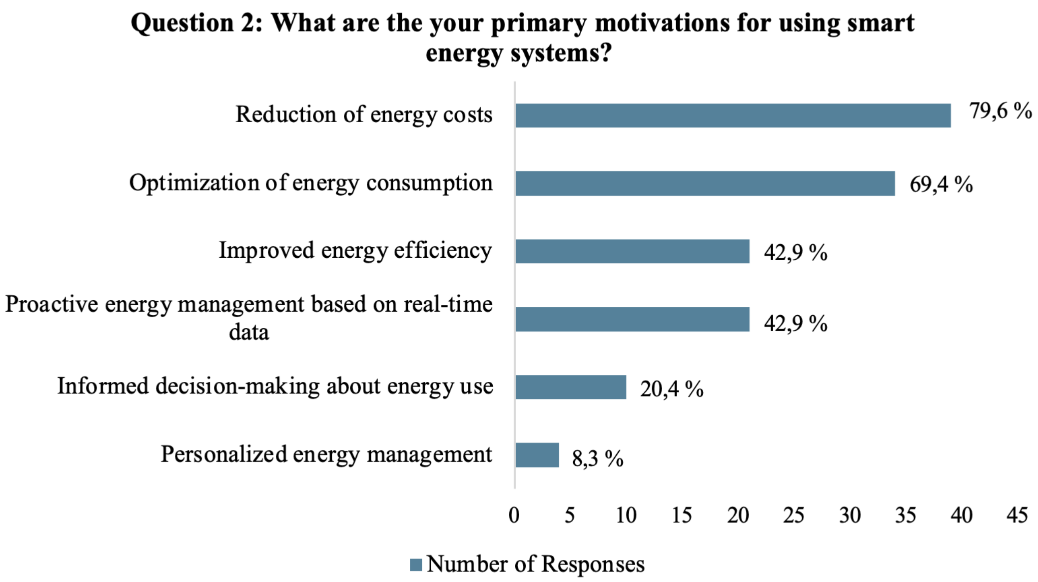

Figure 1: Primary Motivations for Using Smart Energy Systems

The participants of the survey themselves also provided suggestions regarding motivations for the use of smart energy systems and therefore delivered interestingly different requirements from these systems. For example, one participant emphasized the role of sustainable energy production, which is in line with bigger environmental motivations for the adoption of smart energy systems. Another participant stated that they look for the improvement of the use of photovoltaics, suggesting a technological interest in harnessing solar energy more effectively. Additionally, the desire to produce and consume energy regionally was mentioned, emphasizing an approach to energy management that is community-oriented and in relation to local production and consumption patterns. These personalized motivations suggest that users are motivated by more than just conventional benefits, and that they are seeking to align their smart energy systems usage with broader ecological principles and personal values.

The explored motivations taken together gave an overall view of the adoption landscape with smart energy systems from a user perspective. This highlights that smart energy system designers should not only focus on the technological aspects of the systems but also the broader preferences, concerns, and environmental values of the users in general. By incorporating features that address these diverse needs and challenges of users, particularly through an enhanced explainability and user-centric design, the implementation of Smart Energy Systems will likely lead to greater acceptance and satisfaction among users.

6.2.2 Explainability and User Perceptions

Through the survey, the concept of explainability emerges as an important factor in influencing user trust and acceptance of smart energy systems. About half of the respondents, with 51%, stated that there is a very high need for providing clear information on energy management decisions, complemented by an additional 36.7% who also recognize its relatively high importance. Only 6.1% of all answers valued clear energy management decisions on a moderate level, while the remaining 6.1% indicated that they saw either little or no necessity for such transparency. This focus on transparency and the need for comprehensible explanations highlights a crucial aspect of user-system interaction, in which understanding how the system works and its reasons for making certain decisions are a crucial part of user satisfaction and trust. The significance attached to explainability is further underlined by the fact that 59.2% of respondents consider it very important for their engagement with smart energy systems, and another 36.7% of respondents consider it to be important. Furthermore, the survey revealed that just 2 of the 49 participants view explainability as not very important, while none of the participants deemed it completely unimportant. This signals a strong user preference for systems that are not only efficient and cost-effective, but at the same time provide transparency and a high level of communication about operational processes and their decision-making criteria.

6.2.3 Conclusion and Future Directions

Considered all together, these findings reflect the complex relationships between the motivators to adopt smart energy systems and the importance that users place on explainability. Initial adoption may be largely driven by economic and efficiency reasons, but continued trust, satisfaction, and engagement with these systems are also influenced by their ability to engage users by providing clear, understandable explanations of how they work. This brings out the need for designers and developers to build explainable features into their systems, making them not only technologically advanced but also user-centred, as supported by Hassija et al.[30]. This approach is likely to increase user confidence and a higher rate of adoption. Ultimately, this will contribute to the wider goals of energy efficiency, cost reduction and environmental sustainability.

6.3 Insights into Implementation Challenges

The responses of the survey do not only shed light on the user experiences and preferences, but also the complications when it comes to smart energy systems, therefore providing a valuable framework for understanding how smart energy systems can be implemented and adopted by a wider range of people more effectively. This exploration begins with the identification of patterns in the challenges and concerns regarding smart energy systems as expressed by the participants. Understanding the limitations faced by users of smart energy systems is important for several reasons. First, it leads to the identification of areas where these systems may not be in line with user needs and expectations. By exploring issues such as the difficulty of understanding system recommendations or behaviors, insights into the level of opacity apparent in smart energy systems can be gained. The number of respondents expressing this as an issue suggests a potential link to existing issues with intransparency. Moreover, addressing these challenges can increase user confidence, encourage wider adoption, and thereby realize the full potential of smart energy technologies.

6.3.1 Critical Limitations and Issues

Despite the clear benefits of smart energy systems, the adoption and user satisfaction with these systems are also affected by a number of challenges. To analyze these issues, the survey participants identified the most significant challenges or limitations they associated with the utilization of smart energy systems. The barriers the survey participants face, ranging from technical difficulties to privacy concerns highlight the specific areas that require attention to improve user experience. Technical difficulties and system reliability concerns have proved to be the most significant challenges. Of the 49 respondents surveyed, 35 (71.4%) identified technical difficulties or failures when using smart energy systems as significant. Such technical issues not only disrupt the functionality of these systems, but also impact user confidence in the technology [31]. The survey findings also demonstrate that 38.8% of respondents still struggle to understand the system's recommendations or behavior. This challenge highlights a broader issue within the design and communication strategies of smart energy systems. If the reasoning behind automated decisions is not made clear, users may feel unable to trust or interact effectively with the system. This lack of understanding can prevent users from fully engaging with the system, potentially leading to a reduced perception of its value [5]. In addition, the interfaces of many smart energy systems lack the intuitive design necessary to facilitate easy user interaction. If users find these interfaces difficult to navigate or non-intuitive, it makes it harder for them to make informed decisions based on the system's recommendations. The lack of explanatory support within these systems exacerbates this problem, leaving users without the necessary tools to understand how their actions affect energy consumption and system efficiency. This issue is further emphasized by the fact that 30.6% of the respondents showed concerns over the clarity of how the smart energy systems impact their energy consumption. This lack of understandable feedback about how actions and changes within those systems are affecting their energy usage represents a barrier to effective energy management and optimization. Users that experience uncertainties over their interactions with smart energy systems could lead to skepticism over the promised cost and environmental benefits of smart energy systems. If the data is more transparent and accurate to the users' consumption, it could make a difference in trust and proactive engagement with such systems. Integration with other smart home devices was another area of concern, with 36.7% of users seeing challenges in integrating smart energy systems with other smart home devices. When devices do not communicate well or work together effectively, affects the overall functionality and convenience, impacting the user experience in a negative way. This limitation might even discourage users from integrating and utilizing smart home systems, seeing these technologies as too inconsistent or complicated for proper management. Addressing this interoperability issue is important to enhance user satisfaction and to enable the full benefits of smart home technologies. Another issue, privacy and security concerns were viewed as significant by 30.6% of respondents. In a time when data breaches are not uncommon, users are concerned about the security of their personal information and the potential for unauthorized access to their energy consumption patterns [32]. This challenge points out the need for robust security measures and transparent communication about how user data is collected, used and protected.

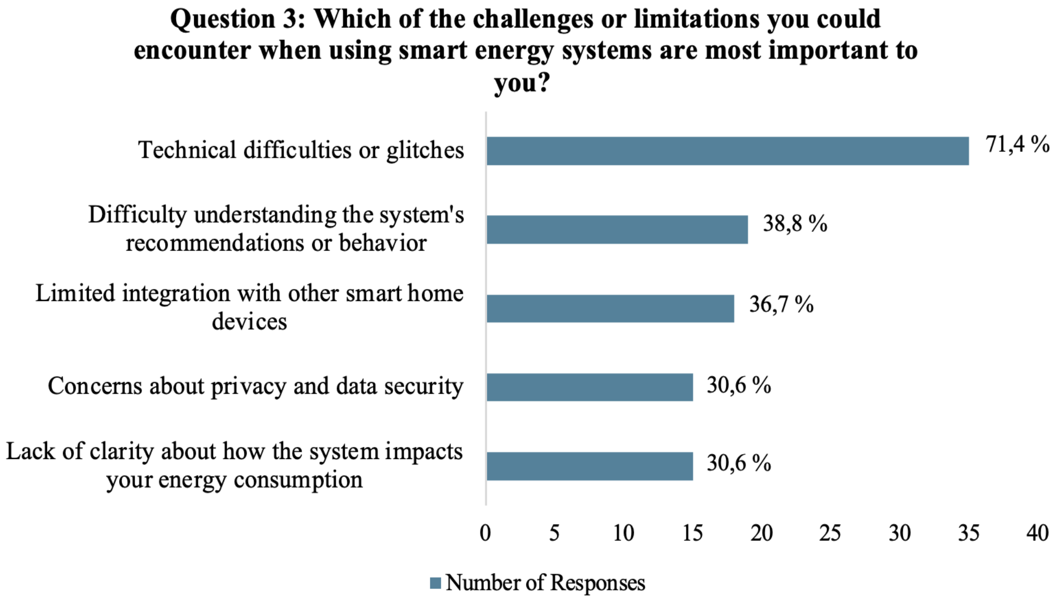

Figure 2: Key Challenges in Using Smart Energy Systems

Additionally, regarding this topic respondents could once again express additional concerns that were not listed. These concerns included slow smart meter data, insufficient network capacity, and uncertainties about the future of the technology, such as what would happen in the event of a user's passing, device discontinuation, or lack of software updates. These issues demonstrate the need for more attention to ensure the long-term viability and user confidence in smart energy systems. It can be concluded from this survey that while the benefits of smart energy systems are clear, their effective implementation and user acceptance depend on overcoming the set of technical, usability, security, and integration challenges. The findings provide an important basis for developing strategies that focus on user-centered design and robust system functionality to ensure that smart energy systems can meet the needs of users and provide a seamless, safe and efficient energy management experience.

6.3.2 Addressing Barriers to Adoption

Given these issues, they should be addressed through an approach that not only prioritizes technical reliability and robust security measures but also focuses on seamless integration and explainability to enhance user interaction and trust. Maintaining the reliability of these systems is essential for their effective operation and long-term efficiency [33]. Strong security measures are also critical to protect user data and build trust in the system's safeguards against unauthorized access [34]. Furthermore, strong encryption and clear privacy policies are essential to protect user data and build trust in new technologies [35]. This is particularly important at a time when data breaches are becoming more and more common and users are increasingly concerned about the privacy of their personal data [35]. Central to this whole approach is the prioritization of explainability. Smart energy systems can be complex, and making their operation transparent and understandable to users is essential for adoption and effective use [5]. For example, the research of Shin [36] emphasizes the role of explainability in building trust in smart energy systems. This research discusses how interfaces that clearly communicate how decisions are made can significantly improve user understanding and satisfaction and that systems designed with explainable AI features not only foster trust, but also encourage users to rely more on these systems for everyday energy management [36] . Taken together, these strategies can improve the effectiveness of smart energy systems, ensuring that they are not only more acceptable, but also more integral to everyday energy management in the home. By addressing technical, security and integration challenges, and especially by emphasizing explainability, these systems can in gain wider acceptance and become deeply integrated into everyday life in a way that users find useful and trustworthy.

6.3.3 Conclusion and Future Directions

Overall, the introduction of smart energy systems is not just accompanied by benefits, but also with challenges that go beyond just technological progress. These challenges address various aspects centered around users, thereby demonstrating the complex relationship between technology and human interaction. Through the survey results, we gained insights into these complexities, discovering the obstacles users encounter, from technical glitches to difficulties integrating with other smart devices. Despite the acknowledged importance of explainability, a lot of users still find it challenging to comprehend system recommendations or behaviors, revealing a gap in user understanding. Therefore, while technological advancements are critical, successful implementation of smart energy systems requires an approach that places user needs and preferences at the forefront. By addressing these challenges, including improving technical reliability, enhancing security measures, and refining explainability, we can ensure the seamless integration and widespread acceptance of smart energy systems.

6.4 Identifying Key User Requirements and Expectations

As previously uncovered, smart energy systems present significant opportunities for energy savings and enhanced living comfort. However, their successful implementation and broad uptake depend not just on advanced technology, but on a deep understanding of user needs and expectations. This section of the paper investigates the core user requirements and expectations that have emerged from the survey. These insights are of great importance, as they not only support the technical and functional aspects of smart energy systems design but also shape the strategies for user interaction, system customization, and long-term user engagement. By focusing on the needs and preferences expressed by potential and current users, developers and designers can ensure that smart energy systems are user-centric, accessible, and trusted by the people and communities they serve. Through a detailed analysis of the survey data, this paper identifies the key aspects of smart energy systems that users value highly and examines how these priorities can be integrated into system design to create higher adoption rates and satisfaction. From customization based on individual lifestyles to the need for clear communication about system functionalities, this exploration demonstrates how aligning with user expectations is not only about enhancing user convenience, but also about building trust and ensuring the effective utilization of smart energy systems.

6.4.1 User Preferences for Clear Information

Incorporating the need for clear information about energy management decisions into the design of smart energy systems is a key aspect of addressing and meeting user requirements and expectations, as supported by the survey results, which show that a vast majority of users (87.7%) consider clear information on energy management decisions as either very important or relatively important. This preference emphasizes that users not only want but even expect systems that provide straightforward and accessible explanations of their decisions. This demand for clarity in energy management aligns with broader user requirements for systems that are intuitive and transparent. Users want to feel assured that they understand how their actions affect energy consumption and cost, which impacts their trust in and satisfaction with the system, as will be further discussed later in the paper. Furthermore, the emphasis on clear information underscores a critical user requirement for empowerment through knowledge. This approach will likely enhance user engagement and improve the system's overall effectiveness by enabling users to make informed decisions about their energy usage. As uncovered by the survey, integrating clear communication as a core design principle addresses the user needs, clearing the way for better energy management practices. Therefore, smart energy system developers should prioritize transparency and simplicity in their designs to effectively meet these user expectations. This emphasis on clear information not only enhances user interface design but also strengthens the relationship between users and technology, creating user confidence and increasing system utilization.

6.4.2 User Demand for Personalized Energy Solutions

One of the main insights from the survey regarding smart energy systems is the demand for customization. A majority of survey respondents indicated that these systems should be highly tailored to individual user needs. In particular, 49% of respondents marked the highest level of agreement, suggesting that smart energy systems should very much be tailored to individual requirements. An additional 40.8% also saw considerable importance to this aspect, although with slightly less intensity. Notably, only 10.2% of respondents felt that customization was of medium importance, while none rated it as low importance or unimportant at all. This highlights a clear preference for personalized smart energy solutions. This inclination towards personalization highlights a critical user requirement: the ability of smart energy systems to adapt to different users and their lifestyles and preferences. The reasoning behind this expectation is straightforward. Energy usage patterns can vary considerably between households, influenced by a number of factors, such as household size, daily schedules, energy habits, and even the specific appliances used. Customizing smart energy systems enables systems to provide insights and recommendations that are directly relevant to each user, rather than generic advice that may be less applicable or effective. This level of personalization not only enhances user satisfaction but also encourages more conscious energy management practices [37]. It is also interesting to note, that while the respondents did not necessarily view personalization as one of the primary benefits provided by existing smart energy systems, they still displayed this strong demand for customization. This observation underscores an important area for improvement and focus. Enhancing the personalization capabilities of smart energy systems should be prioritized to better meet users' needs and expectations.

6.4.3 Emphasis on Transparent Communication

The survey results not only support the need for information about energy management decisions, but also indicate the necessity for transparent communication about the functionality of energy management tools. A significant 71.4% of respondents see clear communication as highly important, and an additional 20.4% find it relatively significant. This demand for clarity and transparency further supports the fact that users expect smart energy to be comprehensible and transparent in their operation and management. When users clearly understand how the system functions and the rationale behind its decisions, their confidence in the reliability and effectiveness of the system increases. This understanding could allow users to utilize the system more effectively and take proactive measures based on the insights provided. Furthermore, clear communication is likely to enhance users' sense of control over their energy management. Users who feel informed about their energy management systems functionality might see themselves as active participants in the process, and not just passive recipients of technology. This approach might help meet user expectations and enhance their overall experience with smart energy systems.

6.4.4 Linking User Understanding to Trust in Technology

Understanding the impact of user comprehension of smart energy systems on their trust in the technology is another factor that is crucial for designing systems that successfully meet user requirements. The survey revealed a connection between the users' understanding of smart energy systems operations and their trust in these systems, with a large part of the respondents acknowledging this impact, where 67.3% viewed it as 'very high' and 22.4% as 'relatively high'. The last 10.2% of users marked the impact of smart energy systems understanding on user trust as 'moderate'. This correlation highlights the need for smart energy systems to prioritize clarity to meet user expectations and foster a level of trust. Therefore, trust in technology, especially in systems that manage critical aspects such as energy consumption, is essential not only for convenience, but for effective operation and user satisfaction. Users need to feel confident in the systems they use, and this confidence at least partly originates from their understanding of how these systems function and the rationale behind their decisions. When users grasp the logic and decision-making processes of smart energy systems, they are more likely to trust these systems' reliability[36]. The absence of respondents indicating low importance of understanding to impact on trust further supports the universal demand for comprehensible and transparent systems. This agreement among users about the importance of their understanding once again suggests that smart energy systems must be designed not only with technical efficiency in mind but also with a focus on user-friendly interfaces that enable easy comprehension and interaction. Providing transparent, intuitive content, such as real-time feedback or detailed operating instructions, can make the technology comprehensible and empower users [38]. Furthermore, incorporating findings from the survey, which included the varying levels of technical expertise among users, the development of smart energy systems should also aim to accommodate these diverse ranges of user knowledge. By providing explanations for users with different levels of technical knowledge, from those with no technical background to experts, these systems can make sure that everyone, no matter their level of prior knowledge, fully understands how their actions affect energy use and system efficiency. This approach is crucial in building user trust and ensuring the technology is accessible and effective for everyone. In summary, the relationship between user understanding and trust in smart energy systems, as illustrated by the survey, requires a user-centric approach to system design. This approach should prioritize transparent communication and educational support as fundamental components of the system, striving to meet the needs and expectations of users. By focusing on these elements, smart energy systems can be created that are not only technically proficient, but also deeply trusted and valued by their users. This will therefore likely lead to higher adoption rates and more effective energy management.

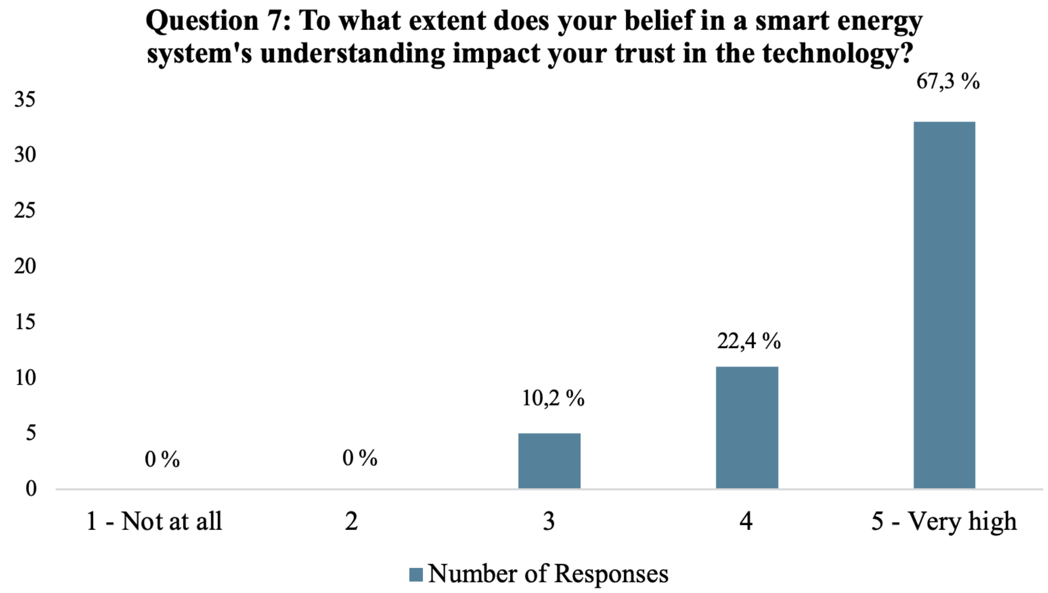

Figure 3: Trust in Smart Energy Systems Based on Understanding

6.4.5 Optimizing User Experience in Smart Energy System Design

The insights gained from exploring user requirements in the context of smart energy systems lead to several important considerations for the design of smart energy systems. First and foremost, the emphasis on customization portrays the need to develop systems that adapt to unique user lifestyles and varying energy usage patterns. The focus should therefore be on creating highly flexible algorithms that learn from and adjust to individual user behaviors, creating personalized energy management solutions [39]. Secondly, the importance of clear communication points to the necessity for user interfaces that are both straightforward to navigate and full of information. Designers are responsible for developing these interfaces to provide users with easy access to detailed explanations of how interactions influence energy consumption. This might be achieved by incorporating tools and aids that simplify complex technical operations and make the systems approachable and manageable for end-users [40]. Thirdly, the link between a user's understanding of the system and their trust in it suggests that building a solid educational foundation should also be of high importance in system design, for example by including informative tutorials or accessible guidance materials. In summary, by embracing these design principles, developers can create smart energy systems that not only meet the technological demands of modern energy management but also meet the practical and everyday needs of end-users. This balance is essential for encouraging increased acceptance and satisfaction among users of smart energy systems.

6.4.6 Conclusion and Future Directions

With the detailed exploration and examination of key user requirements and expectations with smart energy systems, distinguishing these insights becomes crucial. This research has shown that the success of smart energy systems depends not only on technology alone but likewise on how well these systems can meet specific user needs. As the results above reveal, there is a strong demand among users for systems that can be personalized and are responsive and transparent. Personalization and clear communication emerged as key elements, with users showing a preference for systems that can adapt to individual characteristics and are straightforward to understand. Moving forward, it will be necessary to encourage the development of systems that focus not just on saving energy but also on supporting users and their requirements. Furthermore, the survey results concerning user understanding of smart energy systems and their trust in these systems underline the significance of educational and supportive programs and tools as additional strategies that could enhance user-system interactions. It becomes clear that once users are equipped with information and options to effectively manage smart energy systems, they are more likely to trust, be satisfied with, and have better interactions with these systems. In conclusion, this examination of user requirements and expectations offers a promising guideline for future development within the field of smart energy systems. It shows that an approach that combines technical innovation with user-centered design, will help ensure that smart energy systems are not only more effective but also more accepted, fulfilling their primary purpose.

6.5 Extracting Insights on Explainability

In the world of smart energy systems, where artificial intelligence and machine learning manage intricate data and automate decision-making processes, the concept of explainability has become one of the key elements of user trust and system transparency [5]. The survey results provided insights into the world of understanding explainability from the perspective of end-users. Essentially, explainability reduces software opacity, enabling users to understand why a system generated a particular outcome [24]. Explainability has a double effect, it enhances users' understanding of how the system works while also fostering confidence and trust in the system, as previously uncovered by the survey results. For users to fully trust smart energy systems, they need to feel like partners with the system rather than feeling disconnected from it. The current push for the explainability of smart energy systems is part of the broader trend within the technology design which acknowledges the need for human-centric values [25]. This section analyzes the survey results to determine users' perspectives on explainability and assess the importance of this topic in their eyes. These insights are intended to support the further development of user interfaces and decision-support tools in smart energy systems. Additionally, these findings could also add value to the conversations in academic and industry circles about explainability, which plays a valuable role in improving system trustworthiness and empowering users.

6.5.1 Importance of Explainability in Smart Energy Systems

The survey results offer a clear indication of the high level of importance users place on explainability in smart energy systems. As previously uncovered, in the topic of smart energy systems, it is crucial to provide clear and understandable information about how energy management decisions are made. Reflecting on the survey findings that were previously examined, it is evident that explainability within smart energy systems is not just preferred but even seen as essential by a majority of users. Respondents rated the importance of clear information in energy management decisions on a scale from 1 (not at all important) to 5 (very important), and the results strongly favored transparency. A significant 51% of respondents stated clear information as 'very important', and an additional 36.7% rated it as 'important'. These responses support the idea that transparency is not just a helpful feature but a necessary expectation for smart energy systems. This call for clear information is part of a broader trend toward improving user understanding and trust in automated systems [36]. It emphasizes that users are not only interested in the outcomes these systems deliver but also in understanding the reasonings behind the decisions. Understanding the reasoning behind energy management decisions boosts users' confidence and satisfaction with the systems, leading to more active and thoughtful engagement in managing their energy usage [36]. The findings of the survey have significant implications for the design of smart energy systems. In essence, they suggest that developers should prioritize making explainability a core aspect of system interfaces. This means designing user interfaces that do more than just display the data, they need to show how decisions are derived in a way that users can easily understand. These interfaces should simplify complex algorithms for all users, regardless of their technical expertise. Such an approach not only makes the system more user-friendly but also empowers users to make informed decisions, which is critical for effective energy management [41]. Ultimately, the high value users place on explainability in smart energy systems calls for a shift in how these technologies are designed and implemented. This alignment of energy management decisions with user-centric values is vital for the acceptance and success of smart energy technologies, promoting a more sustainable and efficient energy future.

Such an agreement among the survey participants clearly suggests that explainability is not only an integral part of smart energy systems but also an issue critical to smart energy systems developers. When directly asked about the importance of explainability in intelligent systems, nearly 60% of respondents rated it as 'very important,' while an additional 36.7% considered it 'important'. This demonstrates that the ability of the system to explain its decisions to its users is an essential element of their interaction with the system. Furthermore, only two respondents indicated that explainability is 'somewhat important', and no one marked it as unimportant. This illustrates how vital explainability is for smart energy systems. These survey responses also suggest that the developers of smart energy systems need to ensure that the systems they design not only work properly from a technical standpoint but are also capable of providing clear explanations to their end-users. Explainability therefore makes the system more accessible for users by letting them see not just the decisions it can make but also the reasoning behind the decisions and how these may work towards their aims of energy management and optimization [5]. This insight will assist developers, as when users trust systems more, they are also more likely to trust their decisions and take advice from them, possibly even adapting their behavior according to the system's advice [36]. They need to consider this information, when deciding on the importance of making smart energy systems more explainable which the survey shows is a top priority for the end-users of smart energy system.

As part of the survey, the participants also expressed what aspects of explainability they value in smart energy systems, highlighting its many benefits. A majority, with 65.3%, agreed that explainability is crucial to understand how these systems function and make decisions. This understanding is vital because it allows users to see the logic of the system, from input through processing to the final decision [5]. The importance of explainability in building trust within smart energy systems is further empirically supported, as a significant 63.3% of survey participants consider the strengthening of trust and enhanced acceptance of decisions to be core benefits associated with explainability. This insight strengthens previous findings that clear communication and explainability are essential for creating user trust in smart energy systems. This transparent communication not only reassures users about the technology's decision making and effectiveness but

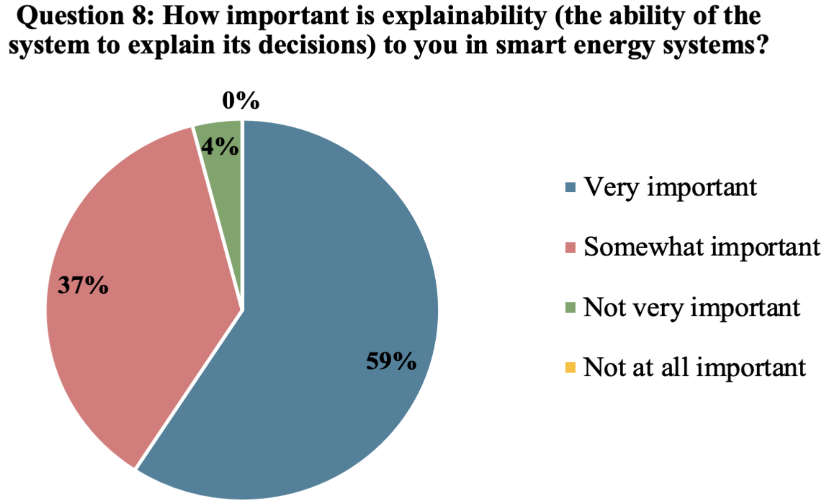

Figure 4: The Importance of Explainability in Smart Energy Systems to Survey Participants

also deepens their trust. This trust comes from a comprehensive understanding of how the system functions, assuring users that the actions taken by the system are predictable and based on sound logic [36]. Additionally, 53.1% of users think of the ability to customize system behavior to meet their specific needs as one of the key benefits or aspects of explainability. As already uncovered, personalization enhances the user experience, and therefore naturally boosts user satisfaction. Furthermore, 46.9% of participants value explainability for offering insights into their energy consumption patterns. This aspect of explainability gives users the possibility to make well-informed decisions about their energy usage, leading to more effective management and possibly even cost savings. Lastly, about one-third of respondents (32.7%), stated that they value explainability for its role in identifying potential issues within the system. This functionality enables users to spot and comprehend errors, promoting a proactive approach to energy management. By knowing what signs to look for and understanding the performance of smart energy systems, users can swiftly address or report issues, helping to keep the system functional. Overall, this section of the survey highlights the critical role of explainability in smart energy systems and the advantages that it brings. By having these aspects in mind when designing these systems, developers can ensure that smart energy solutions not only meet technical standards but also closely align with user expectations and preferences.

6.5.2 Factors Influencing Trust in Smart Energy Systems

Another aspect examined in the survey was the factors that influence user trust and acceptance of the explanations provided by smart energy systems. Participants ranked the influence of clarity, personalization, insightfulness, and relevance on the explanations these systems offer. Notably, clarity and conciseness emerged as the top factors influencing trust and acceptance in explanations, with 32 respondents ranking these qualities as the most important. Clear and concise explanations allow users to quickly understand the rationale behind system decisions. Therefore, when explanations are straightforward and easy to understand, users tend to feel more trust and acceptance towards these systems. Personalization of explanations was also highlighted as important, with 16 respondents ranking it as their second most significant factor. This further demonstrates that users appreciate explanations that are tailored to their individual needs and existing knowledge. Personalized explanations take the user's background, preferences, and previous interactions with the system into account, making the information more relevant and simpler to understand. This customization enhances the effectiveness of the system by ensuring that the explanations speak directly to each user, thereby deepening user engagement and trust with the technology. Additionally, the ability of explanations to provide deep insights into why decisions are made by the system was noted as another key factor, enabling users to fully understand the underlying reasons behind the system's actions. Fifteen respondents in the survey ranked the importance of receiving clear insights on the systems decisions through explanations as the second most influential factor, while 20 respondents considered it the third most important. Lastly, the survey results revealed that the factor least prioritized by respondents was the relevance of explanations to their existing understanding of energy management and consumption. Specifically, 27 respondents ranked this aspect as the least influential. This finding suggests that while some users appreciate explanations that align with their existing knowledge, the majority might not prioritize alignment with pre-existing beliefs as highly as other factors like clarity and personalization. The overall ranking suggests that the essential factors impacting trust and acceptance in explanations, such as clarity, personalization, and insightfulness, should be the primary focus for smart energy systems to meet user expectations and needs effectively. In conclusion, the results from this survey section indicate that trust in and acceptance of explanations are heavily influenced by the quality of the explanations provided. Users expect these explanations to be clear, personalized, insightful, and relevant, which are essential factors that system designers must address to ensure the technology aligns with the needs and expectations of its users.

6.5.3 User Preferences in Explanation Formats

The survey results revealed significant insights into how users prefer explanations that help them understand smart energy systems. The responses revealed a strong preference for visual methods of communication, reflecting a broader user desire for more engaging interfaces. Visual explanations, such as diagrams, charts, and dashboards, were favored by 57.1% of respondents. This preference highlights the effectiveness of visual aids in making complex information easier to understand. These tools help users quickly grasp patterns and system behaviors without needing to study long texts or complex figures. By presenting information graphically, these systems can highlight key details and trends that might be overlooked in text-based explanations, thereby enhancing user understanding of the system. Interactive explanations, including interactive visualizations that allow users to explore data, was another preferred explanation, as chosen by 49% of respondents. This preference indicates that users value the ability to actively engage with information. Interactive tools empower users to delve deeper into their energy usage patterns and the system's recommendations, which can lead to more informed energy management decisions. Chatbots also emerged as a noteworthy form of explanation, chosen by 28.6% of participants. Chatbots offer a conversational interface, making the technology seem more approachable and user-friendly. They provide quick answers and can guide users through the system's features and functionalities in a dialogue-driven manner. This format might be appealing for users who prefer personalized responses and may feel more comfortable asking questions in a conversational setting rather than navigating through menus or reading manuals. Text-based, static explanations were the least popular among the survey respondents, chosen by 18.4%. This indicates that although some users still appreciate straightforward, textual information, there is a clear trend toward more engaging communication methods. Text-based explanations may not be as effective at capturing user attention or facilitating understanding as more interactive or visually appealing tools. Despite their lower popularity, text-based explanations still have an essential role, particularly given that the most preferred choice in explanations was the combination of text-based, visual, and interactive explanations, selected by 59.2% of respondents. This combination suggests that while users appreciate the clarity and directness of text explanations, they also need the depth and engagement that visual and interactive elements provide. Integrating multiple formats can accommodate a wider range of learning styles and user preferences, making the system's operations more understandable to a diverse user base. In summary, the expressed preferences highlight a significant trend towards more dynamic and user-friendly explanation formats in smart energy systems. Users not only seek clarity and insight from the explanations provided but also value interactive and visually engaging methods that enhance their understanding and control over the system. This feedback is particularly for system designers aiming to improve user satisfaction and engagement, suggesting that a combinational approach that uses various explanatory formats could be most effective in meeting user needs. Integrating chatbots into this mix offers an additional layer of interactivity, speaking to those who favor a more conversational and responsive interface. In addition to the main preferences in explanations, the survey also captured unique responses among participants. Video explanations were named, emphasizing the appeal of multimedia presentations to display complex information. Another participant preferred personal conversations with people, suggesting a desire for direct human interaction to clarify doubts. Lastly, one participant mentioned real-time data visualization and status updates. Each of these responses, further underscores the diverse ways users wish to receive information, pointing to the importance of accommodating the various preferences in smart energy systems.

6.5.4 Integrating Explainability into System Design

In the context of explainability, the survey results not only align with the existing literature but also unveil new insights into its critical role, especially within smart energy systems. The results highlight its significance in fostering user trust and ensuring system transparency, which is essential for end-user engagement. A notable majority of users demand clear and intelligible explanations from their intelligent energy systems, reflecting a broader expectation for user-friendly technology. These findings add to the academic discourse, particularly by illustrating how explainability directly influences user satisfaction and trust in technology. This aligns with insights from Adadi and Berrada [42], who discuss the growing necessity for transparency in intelligent systems, underscoring the practical implications of these theories in real-world applications. The survey also revealed that participants highly value clear information about energy management decisions in smart energy systems, which further supports the argument for transparency as a key factor in technology trust. Trust emerged as a critical theme, not developed automatically but through repeated interactions where the system's functions and logic are made transparent. This is supported by research that regards trust as foundational to user reliance and satisfaction with technology, especially in domains as critical as energy management [43]. Considering these findings, the path forward for smart energy systems is clearly influenced by the need for explainability that is built into the design process as a base principle. The survey underscores the necessity to prioritize interfaces that are transparent, intuitive, and responsive, paving the way for a future where technology solutions are aligned with user needs and cognitive habits [44]. In conclusion, the survey's insights and their alignment with existing literature reaffirm the role of explainability in the development of smart energy systems. By adopting design principles that prioritize user understanding, control, and engagement, we can anticipate a future where the relationship between users and their intelligent systems is defined by a mutual understanding. The call for design that incorporates these insights is clear, establishing the foundation for a user-centric evolution in the world of smart energy management.

6.5.5 User Demographics and Explainability Needs

Lastly, for a thorough analysis user demographics were also considered, to delve into how different groups perceive and interact with smart energy systems. These findings further support the importance of implementing personalized and inclusive design strategies that align with the diverse user needs and preferences. Particularly significant was the consideration of respondents' technical expertise. Even among respondents with considerable technical proficiency, where only 10.2% claimed to have no technical knowledge, 38.8% stated a basic knowledge of energy concepts, and the majority (51%) indicated a higher level of technical proficiency, issues of intransparency still persist, alongside with the demand for explainability. This highlights a significant challenge. If those with basic or high technical knowledge already encounter difficulties in understanding these systems, it is reasonable to assume that users with limited or no technical expertise will face even greater difficulties. The study emphasizes the need for designing smart energy systems that are accessible to everyone, regardless of their technical background. Their widespread adoption depends on these systems' ability to offer clear and understandable explanations of their operations and recommendations, and this level of clarity is crucial for fostering trust and acceptance among users of varying backgrounds. Prioritizing explainability in both the design and implementation of smart energy systems is vital. Ultimately, by ensuring transparency in system operations and tailoring communication to suit diverse user needs, these technologies can gain broader acceptance across various demographic segments. This user-centric approach is pivotal in overcoming adoption barriers and unlocking the full potential of smart energy solutions.

7 Conclusion and further research

The exploration of explainability within smart energy systems has revealed deep insights into how users interact with, trust, and accept these systems. This research emphasizes the critical importance of explainability as a link between complex technology and users' understanding, essential for building trust and encouraging active participation. Through surveying and analysis, the study captured users' preferences and expectations regarding the usability of smart energy systems. As for the first research question, the survey outcomes shed light on the specific needs and expectations of end users when engaging with smart energy systems. Users expressed a strong desire for clear and transparent communication regarding the functionalities of energy management tools. They expect these systems to provide understandable explanations that enhance their comprehension and management of energy consumption patterns. Furthermore, users identified the various benefits that they expect smart energy systems to come with, including optimizing energy consumption, reducing energy costs, and improving energy efficiency. These findings underscore the multifaceted expectations users have, encompassing both practical benefits and a clear understanding of system functionalities. As for the second research question, the research also explored the role of explainability in building trust, which emerged as a foundational element for the acceptance and effective use of any technological system, especially those as integral as smart energy systems. The findings revealed that when systems transparently communicate their processes and decision-making reasonings, users feel more confident in their reliability and are more likely to trust the technology's recommendations. Additionally, the research highlighted the importance of personalization in explainability. Systems that adapt their communications to the individual's level of understanding and preferences can notably enhance user engagement. This suggests that future developments in smart energy systems should continue to focus on enhancing explainability. This involves not only improving the clarity of the information presented but also ensuring that these explanations are contextually relevant and aligned with user needs. Addressing the last research question, it is evident that users not only expect these systems to effectively manage energy but also to be understandable and adapted to their needs. The strong preference for visual and interactive communication methods reflects a broader desire for interfaces that are engaging and easy to use. Such features can make the complexity of smart energy systems more approachable, helping the users to make informed decisions based on the system's feedback and recommendations. Furthermore, the implications of this research reach beyond individual user interactions with smart energy systems, as they explore future technologies in the energy sector, emphasizing the importance of a user-centered approach in shaping new systems. These findings are crucial not only to meet technical efficiency standards but also to ensure that new advancements are designed with the end-user in mind. In conclusion, this research reaffirms the importance of explainability in smart energy systems as a significant factor for enhancing user trust, satisfaction, and system usability. It calls for a continued focus on user-centric design principles that prioritize clear, comprehensible, and personalized communication for the future development of smart energy technologies. By bridging the gap between advanced technology and user accessibility, smart energy systems can achieve their full potential, leading to more sustainable and efficient energy management practices that users can trust and rely on.

When considering the future of smart energy systems, several developments stand out as essential for advancing in the field and maximizing the benefit to both users and the environment. As technology continues to progress and the Internet of Things (IoT) becomes more integrated into energy management, there will be a greater focus on creating energy solutions that are personalized to meet each person's specific needs and preferences [45]. By using data analytics, IoT devices, and smart technologies, energy providers can offer customized energy services, optimize energy usage, and empower consumers to make informed decisions about their energy consumption [45]. Furthermore, the importance of robust security measures cannot be overstated. With an increasing reliance on data-driven operations, safeguarding user data against breaches will be of highest significance for maintaining trust and integrity within smart energy systems [32]. Future developments will need to focus on implementing stronger security protocols and ensuring compliance with evolving data protection regulations to preserve user confidence and system reliability. It is highly likely that explainability will remain relevant and increasingly important in the future. Explainability in artificial intelligence is becoming increasingly relevant and is expected to continue to be crucial in the future, especially in complex systems like smart energy systems [46]. The transparency provided by explainable AI is essential for building trust, understanding model decisions, and ensuring accountability in various applications, including smart energy systems [46].

The exploration of the survey mainly centered on the end user's perspective of explainability in smart energy systems. While this perspective is crucial for understanding user needs and preferences, there are other perspectives that call for further exploration. For example, investigating the perspectives of energy system developers, policymakers, and energy industry stakeholders could provide valuable insights into the design, regulation, and implementation of smart energy systems. Additionally, considering the perspectives of environmental advocates, community leaders, and other relevant stakeholders could shed light on the broader societal implications and acceptance of smart energy technologies. Exploring these diverse perspectives could lead to a more comprehensive understanding of the challenges and opportunities associated with smart energy systems, ultimately guiding their development and adoption in a more holistic manner.

A Survey Results

This section provides detailed information about the survey, including the results and additional figures.

A.1 Survey Questions and Responses

Introduction: Smart Energy Systems intelligently manage energy users and producers, aiming for an optimal outcome for all involved. In an energy community, these systems can automate decisions, such as scheduling electric vehicle charges, enhancing grid stability, and providing cost-effective solutions for users. This control system offers numerous benefits, including reduced electricity costs for energy community members and enhanced grid stability for operators. As these decisions are automated, understanding the underlying reasoning becomes crucial. The term 'explainability' describes the system's ability to clarify its decision-making processes. For instance, in a smart thermostat, if it unexpectedly raises the temperature causing higher costs, a clear explanation allows users to understand the decision and make adjustments if necessary. This survey seeks to uncover user preferences for system explainability by exploring the significance of various aspects.

1. Do you have smart energy systems in your home or community? (i.e. energy management system, smart heating devices, electric vehicle charging scheduler, etc.)

   Yes = 69.4%
   No = 30.6%

2. What are the your primary motivations for using smart energy systems?

   Please select the motivations that you consider most significant (maximum of 3).

   Optimization of energy consumption = 69.4%
   Informed decision-making about energy use = 20.4%
   Reduction of energy costs = 79.6%
   Improved energy efficiency = 42.9%
   Personalized energy management = 8.2%
   Proactive energy management based on real-time data = 42.9%
   Other (please specify)

3. Which of the challenges or limitations you could encounter when using smart energy systems are most important to you?

   Please select the challenges that you consider most significant (maximum of 3).

   Difficulty understanding the system's recommendations or behavior = 38,8%
   Lack of clarity about how the system impacts your energy consumption = 30,6%
   Concerns about privacy and data security = 30,6%
   Technical difficulties or glitches = 71,4%
   Limited integration with other smart home devices = 36,7%
   Other (please specify)

4. Rank the statements below from 1 (Not at all) to 5 (Very)

   To what extent do you value clear information about energy management decisions?

   Number 5 (Very) = 51%
   Number 4 = 36,7%
   Number 3 = 6,1%
   Number 2 = 4,1%
   Number 1 (Not at all) = 2%

5. Rank the statements below from 1 (Not at all) to 5 (Very)

   To what extent do you believe that smart energy systems should be adaptable to the unique requirements of each user?

   Number 5 (Very) = 49%
   Number 4 = 40,8%
   Number 3 = 10,2%
   Number 2 = 0%
   Number 1 (Not at all) = 0%

6. Rank the statements below from 1 (Not at all) to 5 (Very)

   To what extent do you believe that clear communication about the functionalities of energy management tools is important for meeting user expectations?

Number 5 (Very) = 71,4%
Number 4 = 20,4%
Number 3 = 6,1%
Number 2 = 2%
Number 1 (Not at all) = 0%

7. Rank the statements below from 1 (Not at all) to 5 (Very)

   To what extent does your belief in a smart energy system's understanding impact your trust in the technology?

   Number 5 (Very) = 67,3%
   Number 4 = 22,4%
   Number 3 = 10,2%
   Number 2 = 0%
   Number 1 (Not at all) = 0%

8. How important is explainability (the ability of the system to explain its decisions) to you in smart energy systems?

   Very important = 59,2%
   Somewhat important = 36,7%
   Not very important = 4,1%
   Not at all important = 0%

9. What could be the benefits or important aspects of explainability?

   Please select the options that you consider most significant (maximum of 3).

   It helps understand how the system works and makes decisions = 65,3%
   It builds trust in the system and increases the acceptance of its recommendations = 63,3%
   It allows the identification of potential issues or problems with the system = 32,7%
   It empowers the customization of the system's behavior to the user's specific needs = 53,1%
   It provides valuable insights into energy consumption patterns = 46,9%

Other (please specify)

10. What factors would influence your trust in and acceptance in explanations?

    Please rank the answers from most influential (1) to least influential (4).

    The explanations are clear, concise, and easy to understand = First place 32 times; Second place 11 times; Third place 2 times; Fourth place 4 times

    The explanations are tailored to my individual needs and knowledge level = First place 5 times; Second place 16 times; Third place 20 times; Fourth place 8 times

    The explanations provide insights into the reasoning behind the system's decisions = First place 4 times; Second place 15 times; Third place 20 times; Fourth place 10 times

    The explanations are consistent with my own understanding of energy consumption and energy management = First place 8 times; Second place 7 times; Third place 7 times; Fourth place 27 times

11. In what format would you prefer to receive explanations from smart energy systems?

    Please select all that apply.

    Interactive chatbots = 28,6%
    Text-based static explanations = 18,4%
    Visual explanations (e.g., graphs, charts, dashboards) = 57,1%
    Interactive visualisations (e.g., visualizations that allow me to explore the data) = 49%
    Combination of text-based, visual, and interactive explanations = 59,2%
    Other (please specify)

12. How would you rate your technical knowledge of energy management?

    No technical knowledge = 10,2%
    Basic knowledge of energy concepts = 38,8%

Higher level of technical expertise = 51%

13. Please indicate your age: Ø 46.63

14. Gender:

    Male = 89.8%
    Female = 10.2%
    Diverse = 0%

15. How long have you been a member of an energy community?

    Less than 6 months = 14.3%
    6 months to 1 year = 26.5%
    1 to 3 years = 53.1%
    More than 3 years = 6.1%

16. How populated is the area you live in?

    Rural town (less than 5,000 inhabitants) = 61,2%
    Small town (5,000 - 20,000 inhabitants) = 26,5%
    Medium-sized town (20,000 - 100,000 inhabitants) = 4,1%
    Large city (over 100,000 inhabitants) = 8,2%

17. If you would be interested in supporting our research with your technical expertise further or would like to know the output of the survey, please leave your e-mail below:

18. If you have any more remarks:

A.2 Survey Dataset

Access the survey response data on Zenodo here: Survey Data

A.3 Additional Charts

This section contains additional charts for those who are interested.

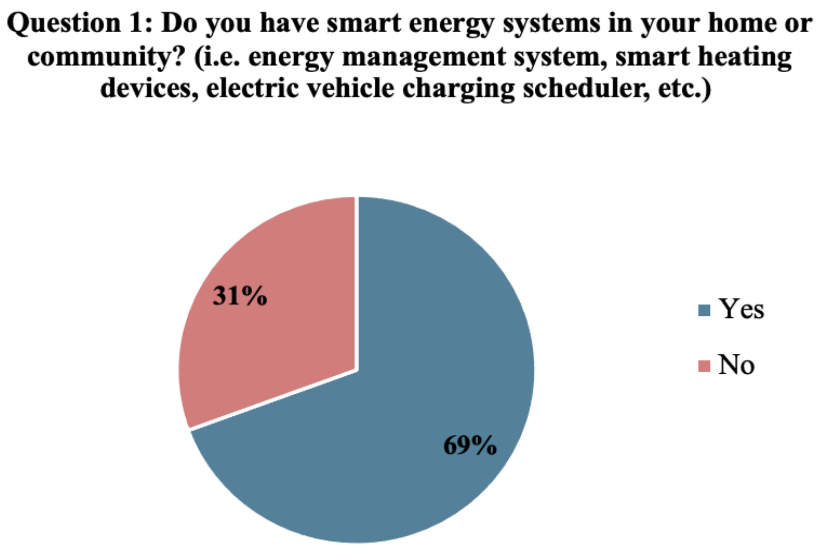

Figure 5: Adoption of Smart Energy Systems

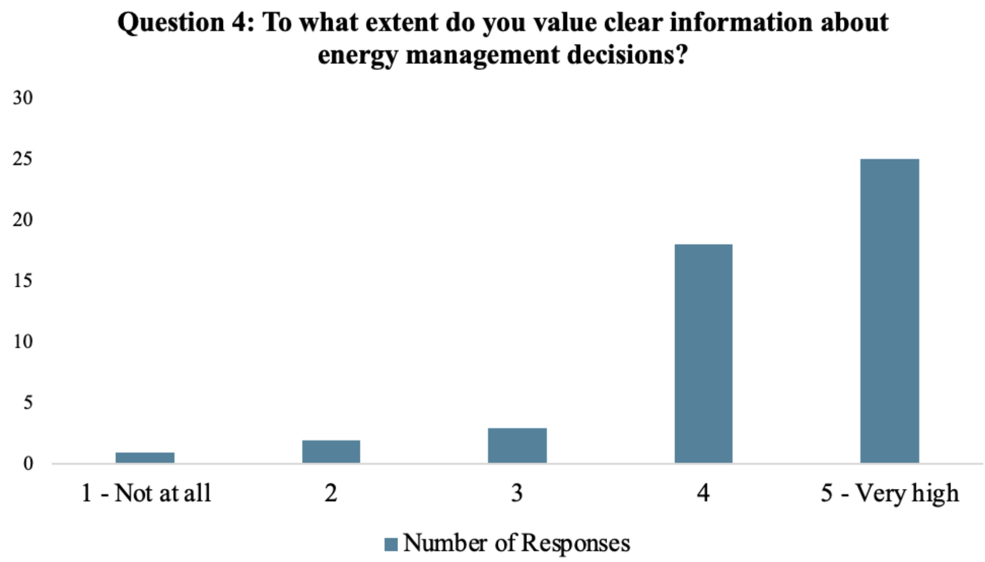

Figure 6: Value of Clear Information about Energy Management Decisions

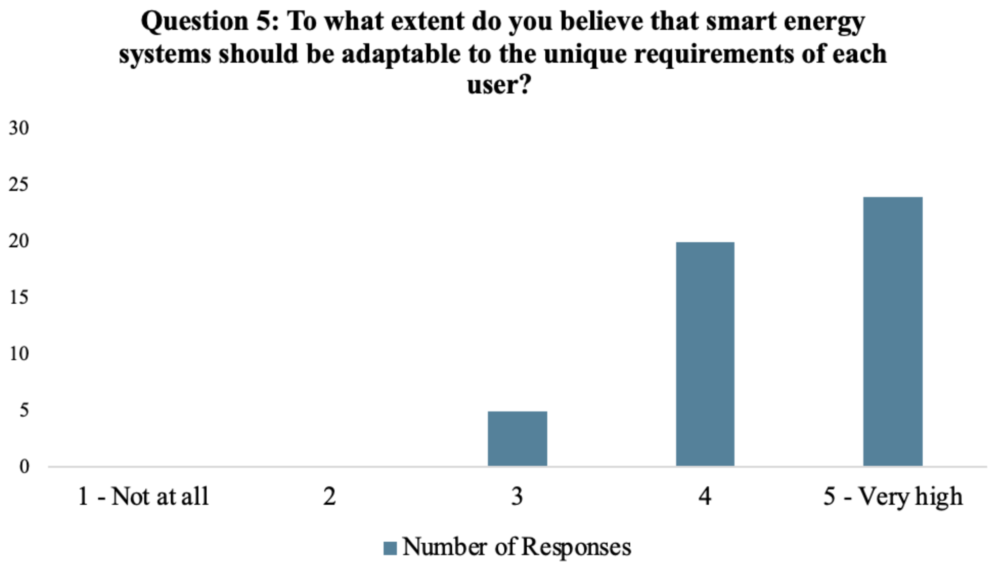

Figure 7: Importance of Adaptability in Smart Energy Systems

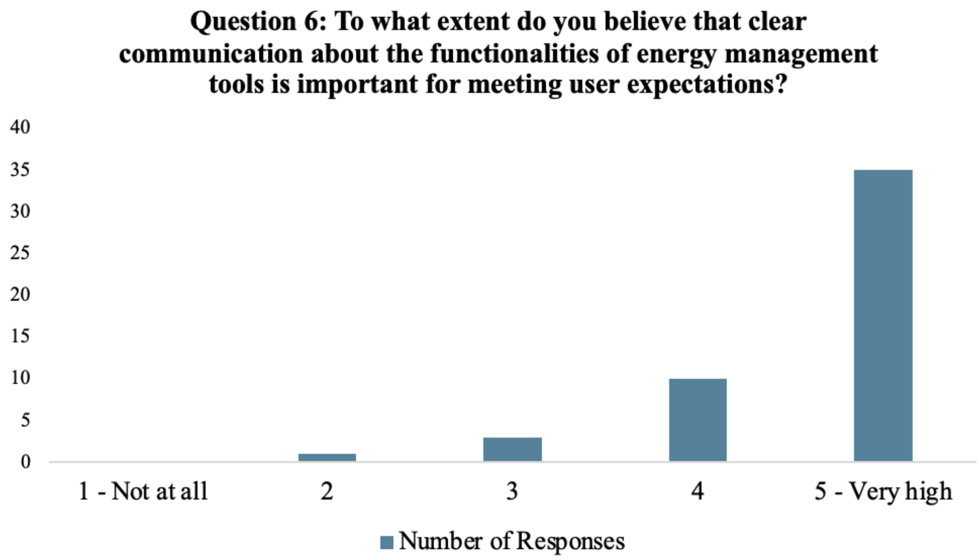

Figure 8: Impact of Clear Communication on User Expectations

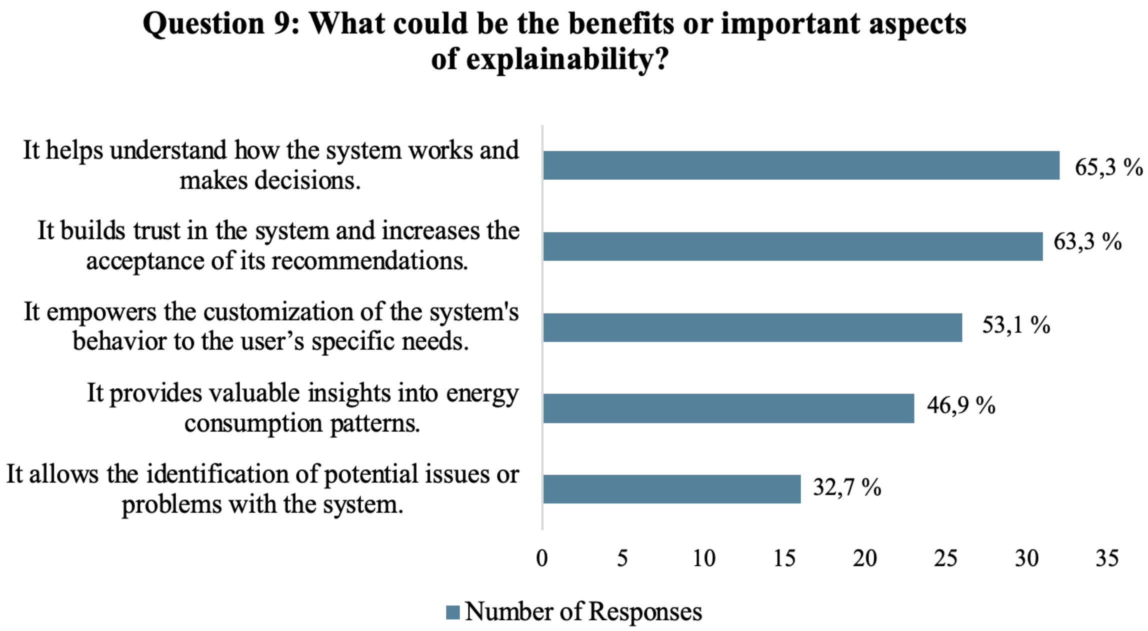

Figure 9: Important Aspects of Explainability

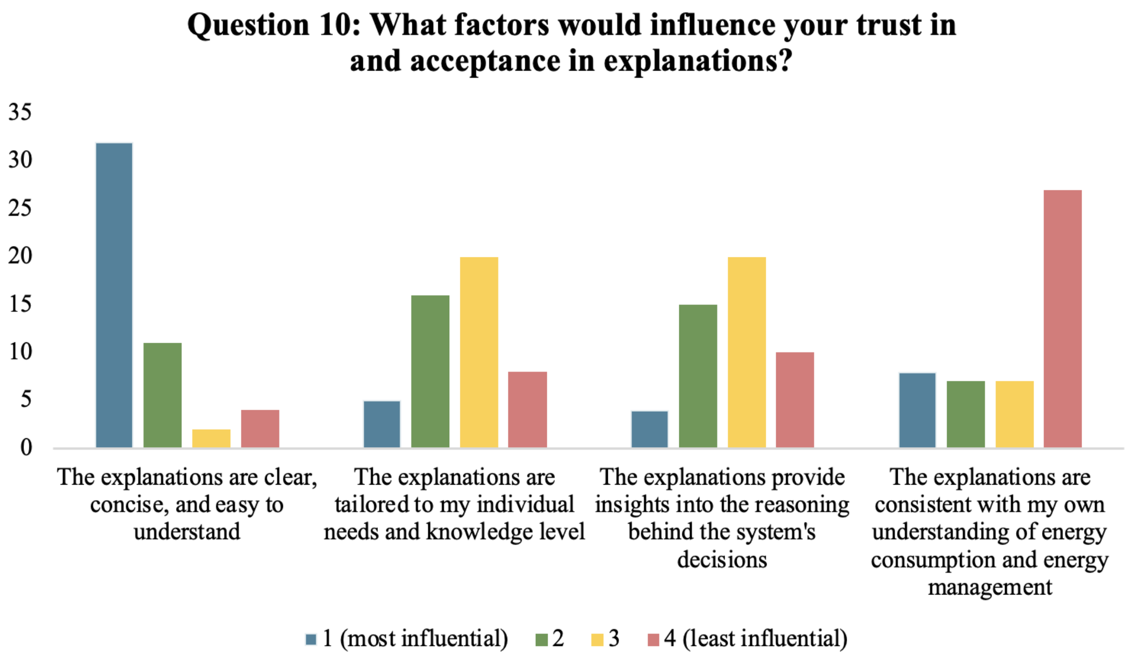

Figure 10: Factors Influencing Trust and Acceptance in Explanations

References

[1] Yizhe Xu, Chengchu Yan, Huifang Liu, Jin Wang, Zhang Yang, and Yanlong Jiang. Smart energy systems: A critical review on design and operation optimization. *Sustainable Cities and Society*, 62:102369, 2020.

[2] Felix N Claessen and Han La Poutré. Towards a european smart energy system. *EIT ICT Labs, Brussels*, 2014.

[3] Esmat Zaidan, Ali Ghofrani, Ammar Abulibdeh, and Mohsen Jafari. Accelerating the change to smart societies-a strategic knowledge-based framework for smart energy transition of urban communities. *Frontiers in Energy Research*, 10:852092, 2022.

[4] Edward O'Dwyer, Indranil Pan, Salvador Acha, and Nilay Shah. Smart energy systems for sustainable smart cities: Current developments, trends and future directions. *Applied energy*, 237:581–597, 2019.

[5] Christos Sardianos, Iraklis Varlamis, Christos Chronis, George Dimitrakopoulos, Abdullah Alsalemi, Yassine Himeur, Faycal Bensaali, and Abbes Amira. The emergence of explainability of intelligent systems: Delivering explainable and personalized recommendations for energy efficiency. *International Journal of Intelligent Systems*, 36(2):656–680, 2021.

[6] Martin Maguire and Nigel Bevan. User requirements analysis: a review of supporting methods. In *IFIP World Computer Congress, TC 13*, pages 133–148. Springer, 2002.

[7] Tom Hargreaves, Michael Nye, and Jacquelin Burgess. Making energy visible: A qualitative field study of how householders interact with feedback from smart energy monitors. *Energy policy*, 38(10):6111–6119, 2010.

[8] Henrik Lund, Poul Alberg Østergaard, David Connolly, and Brian Vad Mathiesen. Smart energy and smart energy systems. *Energy*, 137:556–565, 2017.

[9] Henrik Lund. *Renewable energy systems: a smart energy systems approach to the choice and modeling of 100% renewable solutions*. Academic Press, 2014.

[10] David Connolly, Henrik Lund, Brian Vad Mathiesen, Poul Alberg Østergaard, Bernd Möller, Steffen Nielsen, Iva Ridjan, Frede Hvelplund, Karl Sperling, Peter Karnøe, et al. Smart energy systems: holistic and integrated energy systems for the era of 100% renewable energy. 2013.

[11] Feng Qian, David Bogle, Meihong Wang, Stratos Pistikopoulos, and Jinyue Yan. Artificial intelligence for smart energy systems in process industries, 2022.

[12] Abiodun E Onile, Ram Machlev, Eduard Petlenkov, Yoash Levron, and Juri Belikov. Uses of the digital twins concept for energy services, intelligent recommendation systems, and demand side management: A review. *Energy Reports*, 7:997–1015, 2021.

[13] Yasir Shahzad, Huma Javed, Haleem Farman, Jamil Ahmad, Bilal Jan, and Muhammad Zubair. Internet of energy: Opportunities, applications, architectures and challenges in smart industries. *Computers & Electrical Engineering*, 86:106739, 2020.

[14] Hongyu Zhu, Hui Hwang Goh, Dongdong Zhang, Tanveer Ahmad, Hui Liu, Shuyao Wang, Shenwang Li, Tianhao Liu, Hang Dai, and Thomas Wu. Key technologies for smart energy systems: Recent developments, challenges, and research opportunities in the context of carbon neutrality. *Journal of Cleaner Production*, 331:129809, 2022.

[15] Gerald Schweiger, Lisa V Eckerstorfer, Irene Hafner, Andreas Fleischhacker, Johannes Radl, Barbara Glock, Matthias Wastian, Matthias Rößler, Georg Lettner, Niki Popper, et al. Active consumer participation in smart energy systems. *Energy and Buildings*, 227:110359, 2020.

[16] Kaitlin T Raimi and Amanda R Carrico. Understanding and beliefs about smart energy technology. *Energy Research & Social Science*, 12:68–74, 2016.

[17] Kaile Zhou, Shanlin Yang, and Zhen Shao. Energy internet: the business perspective. *Applied energy*, 178:212–222, 2016.

[18] Eva Heiskanen and Kaisa Matschoss. Consumers as innovators in the electricity sector? consumer perceptions on smart grid services. *International journal of consumer studies*, 40(6):665–674, 2016.

[19] Faiaz Ahsan, Nazia Hasan Dana, Subrata K Sarker, Li Li, SM Muyeen, Md Firoj Ali, Zinat Tasneem, Md Mehedi Hasan, Sarafat Hussain Abhi, Md Robiul Islam, et al. Data-driven next-generation smart grid towards sustainable energy evolution: techniques and technology review. *Protection and Control of Modern Power Systems*, 8(3):1–42, 2023.

[20] R Machlev, L Heistrene, M Perl, KY Levy, J Belikov, S Mannor, and Y Levron. Explainable artificial intelligence (xai) techniques for energy and power

systems: Review, challenges and opportunities. *Energy and AI*, 9:100169, 2022.

[21] Max Unterbusch, Mersedeh Sadeghi, Jannik Fischbach, Martin Obaidi, and Andreas Vogelsang. Explanation needs in app reviews: Taxonomy and automated detection. In *2023 IEEE 31st International Requirements Engineering Conference Workshops (REW)*, pages 102–111. IEEE, 2023.

[22] M Humayun Kabir, Khondokar Fida Hasan, Mohammad Kamrul Hasan, and Keyvan Ansari. Explainable artificial intelligence for smart city application: a secure and trusted platform. In *Explainable Artificial Intelligence for Cyber Security: Next Generation Artificial Intelligence*, pages 241–263. Springer, 2022.

[23] Weiping Ding, Mohamed Abdel-Basset, Hossam Hawash, and Ahmed M Ali. Explainability of artificial intelligence methods, applications and challenges: A comprehensive survey. *Information Sciences*, 615:238–292, 2022.

[24] Larissa Chazette, Wasja Brunotte, and Timo Speith. Exploring explainability: a definition, a model, and a knowledge catalogue. In *2021 IEEE 29th international requirements engineering conference (RE)*, pages 197–208. IEEE, 2021.

[25] Roba Alsaigh, Rashid Mehmood, and Iyad Katib. Ai explainability and governance in smart energy systems: a review. *Frontiers in Energy Research*, 11:1071291, 2023.

[26] Sari Kujala, Marjo Kauppinen, and Sanna Rekola. Bridging the gap between user needs and user requirements. In *Advances in Human-Computer Interaction I (Proceedings of the Panhellenic Conference with International Participation in Human-Computer Interaction PC-HCI 2001), Typorama Publications*, pages 45–50. Citeseer, 2001.

[27] Neil Maiden. User requirements and system requirements. *IEEE software*, 25(2):90–91, 2008.

[28] Michael DeBellis and Christine Haapala. User-centric software engineering. *IEEE Expert*, 10(1):34–41, 1995.

[29] Andrea Ferrario and Michele Loi. How explainability contributes to trust in ai. In *Proceedings of the 2022 ACM Conference on Fairness, Accountability, and Transparency*, pages 1457–1466, 2022.

[30] Vikas Hassija, Vinay Chamola, Atmesh Mahapatra, Abhinandan Singal, Divyansh Goel, Kaizhu Huang, Simone Scardapane, Indro Spinelli, Mufti Mahmud, and Amir Hussain. Interpreting black-box models: a review on explainable artificial intelligence. *Cognitive Computation*, 16(1):45–74, 2024.

[31] Silvia Barbero and Amina Pereno. Systemic energy grids: A qualitative approach to smart grids. *Sustainability: The Journal of Record*, 6(4):220–226, 2013.

[32] Song Tan, Debraj De, Wen-Zhan Song, Junjie Yang, and Sajal K Das. Survey of security advances in smart grid: A data driven approach. *IEEE Communications Surveys & Tutorials*, 19(1):397–422, 2016.

[33] Khosrow Moslehi and Ranjit Kumar. A reliability perspective of the smart grid. *IEEE transactions on smart grid*, 1(1):57–64, 2010.

[34] Adnan Anwar and Abdun Naser Mahmood. Cyber security of smart grid infrastructure. *arXiv preprint arXiv:1401.3936*, 2014.

[35] Matthew David Smith and M Elisabeth Paté-Cornell. Cyber risk analysis for a smart grid: How smart is smart enough? a multiarmed bandit approach to cyber security investment. *IEEE Transactions on Engineering Management*, 65(3):434–447, 2018.

[36] Donghee Shin. The effects of explainability and causability on perception, trust, and acceptance: Implications for explainable ai. *International Journal of Human-Computer Studies*, 146:102551, 2021.

[37] Christian Beckel, Leyna Sadamori, Thorsten Staake, and Silvia Santini. Revealing household characteristics from smart meter data. *Energy*, 78:397–410, 2014.

[38] Chandra Prakash Paneru and Ari KM Tarigan. Reviewing the impacts of smart energy applications on energy behaviours in norwegian households. *Renewable and Sustainable Energy Reviews*, 183:113511, 2023.

[39] Sweatha Rachel George, Aryadevi Remanidevi Devidas, and Maneesha Vinodini Ramesh. Smart personalized learning system for energy management in buildings. In *2017 International Conference on Computation of Power, Energy Information and Commuincation (ICCPEIC)*, pages 036–042. IEEE, 2017.

[40] Marco Jahn, Marc Jentsch, Christian R Prause, Ferry Pramudianto, Amro Al-Akkad, and Rene Reiners. The energy aware smart home. In *2010 5th*

international conference on future information technology, pages 1–8. IEEE, 2010.

[41] Cheng Fan, Fu Xiao, Chengchu Yan, Chengliang Liu, Zhengdao Li, and Jiayuan Wang. A novel methodology to explain and evaluate data-driven building energy performance models based on interpretable machine learning. *Applied Energy*, 235:1551–1560, 2019.

[42] Amina Adadi and Mohammed Berrada. Peeking inside the black-box: a survey on explainable artificial intelligence (xai). *IEEE access*, 6:52138–52160, 2018.

[43] John D Lee and Katrina A See. Trust in automation: Designing for appropriate reliance. *Human factors*, 46(1):50–80, 2004.

[44] Marco Tulio Ribeiro, Sameer Singh, and Carlos Guestrin. " why should i trust you?" explaining the predictions of any classifier. In *Proceedings of the 22nd ACM SIGKDD international conference on knowledge discovery and data mining*, pages 1135–1144, 2016.

[45] Adil Wazeer and Apurba Das. Recent developments in the smart energy systems. *Handbook of Smart Energy Systems*, pages 1–19, 2022.

[46] MK Nallakaruppan, Nathan Shankar, Prahal Bhagavath Bhuvanagiri, Sanjeevikumar Padmanaban, and Surbhi Bhatia Khan. Advancing solar energy integration: Unveiling xai insights for enhanced power system management and sustainable future. *Ain Shams Engineering Journal*, page 102740, 2024.