Filling the Information Gap: A Design Case Study of A Recommender for Home Energy System

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Yanwei Miao

(1627738)

yanwei.miao@student.uni-siegen.de

u. Dorfstraße 130, Siegen

Under the supervision of

Prof. Dr. Gunnar Stevens

Dr. Songmin Yu

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ABSTRACT

The transition to clean energy and energy-efficient technologies is crucial for reducing carbon emissions and mitigating climate change. However, households lack sufficient knowledge and guidance on these technologies, including the potential benefits that can be obtained through their adoption. This study aims to fill the information gap and support decision-making on the adoption of clean energy and energy technologies for homeowners by introducing a novel IT artefact, a personalised home energy system recommender. Meanwhile, this study also seeks to develop effective explanations within a recommender system that fosters trust and facilitates knowledge acquisition, thereby assisting households in making sustainable decisions.

This study employs Design Case Studies within the framework of Grounded Design. Pre-study activities involved online searches and literature reviews. The subsequent concept development phase focused on a constructivism-aligned approach. There has been two evaluations performed in this study, formative evaluation before actual programming and summative evaluation after the online deployment of the service. Qualitative user studies were conducted during the summative evaluation to assess the artefact's effectiveness, emphasising two critical aspects: Knowledge Enhancement: Evaluating users' augmentation of understanding regarding energy technologies and their benefits. Trust in Recommendations: Building users' confidence in the system's suggestions.

The results highlight that the provision of information significantly influences homeowners' decision-making, with slight variations in user responses. The service offered three levels of explanations, with financial and usage pattern explanations being well-received by users. On the other hand, educational explanations focusing on climate change appear less appealing to many. Furthermore, the results offer insights into financial considerations, motivations, trust, personalisation concerns, and the need for comprehensive information. In essence, this study unveils multifaceted insights through the lens of the developed IT artefact, providing an understanding of various dimensions related to homeowners' decision-making in adopting energy technologies.

Contents

List of Figures

List of Tables

Notations and Abbreviations

CO_2 Carbon dioxide. 1, 58, 61, 70

EU European Union. xviii, 2

GHG Greenhouse gas. 1

HP Heat pump. 27

IV Information Visualisation. 28

NL Natural language. 28

PV Photovoltaic. i, 6, 16, 17, 27, 37, 38, 56, 58, 59, 63

RE Renewable energy. 10

RS Recommender systems. 9, 10, 20, 22

SD Sustainabe Development. 10

SEMS Smart energy management system. 17, 27, 37, 57, 59, 60

Chapter 1

Introduction

1.1 Background

Human-induced climate change is causing dangerous and widespread disruption in nature, thereby affecting billions of lives globally [34]. To tackle climate change and its negative impacts, two main strategies are addressed: climate change mitigation and adaptation.

- **Climate change mitigation** refers to the actions taken to reduce or prevent greenhouse gas (GHG) emissions and ultimately stabilise the concentration of these gases in the atmosphere to limit global warming and its adverse effects [47]. This goal entails a range of related projects, spanning farming, land use, peatland management, renewable energies, and energy efficiency. Integrated projects that implement climate change mitigation strategies and action plans at regional or national levels are also pertinent [17]. Notably, to curb carbon dioxide (CO_2) emissions in the energy system, two main approaches are pursued: *(1) reducing energy consumption on the demand side through efficiency improvement and behavioral changes and (2) transitioning to renewable energy sources on the supply side.*
- **Climate change adaptation** encompasses measures to manage the adverse impacts of climate change, such as natural disasters, changes in precipitation patterns, and rising sea levels, among others [47], which includes projects relating to urban adaptation and land-use planning, infrastructure resilience, sustainable water management in drought-prone

areas, flood and coastal management, as well as the resilience of the agricultural, forestry, and tourism sectors [17].

The work in this thesis belongs to the category of climate change mitigation.

The Paris Agreement, a historic international agreement, sets long-term goals to substantially reduce global emissions and limit the global temperature increase to 2 degrees Celsius in this century [56]. To achieve this ambitious goal, the world is facing an unprecedented imperative to a rapid transition in the energy sector. The European Union (EU)'s "Energy 2020. A strategy for competitive, sustainable and secure energy" and "Energy Roadmap 2050" are key strategy papers guiding energy developments in the EU [38], aiming to lead in global climate action and achieve net-zero emissions by 2050 through a socially-fair and cost-efficient transition [16].

The residential sector is a crucial component of the energy transition, as they are responsible for a significant proportion of final energy consumption in the EU, as highlighted by Eurostat's 2023 report. In fact, in 2020, the residential sector accounted for 27.4% of total final energy consumption or 18.7% of gross inland energy consumption in the EU [18]. Therefore, reducing energy consumption in households through energy-efficient building construction and renovations, as well as digitalisation and smart demand-side management, can have a significant impact on achieving the EU's energy and climate targets [32]. This underscores the importance of developing and implementing effective policies and strategies to promote energy efficiency and renewable energy use in households to facilitate the energy transition.

Technologies for home energy systems have rapidly advanced in recent years, with a growing focus on energy efficiency and renewable energy sources. Smart home technologies, such as energy management systems, allow households to optimise their energy consumption and reduce waste. Moreover, rooftop solar panels and home battery storage systems enable households to generate and store their own renewable energy, reducing dependence on the grid and lowering electricity bills. In addition, the integration of electric vehicles with home energy systems can further reduce household carbon emissions and provide a source of backup power. These technologies have the potential to significantly transform the way households consume and generate energy, contributing to a more sustainable and resilient energy system.

1.2 Theoretical basis

Despite the growing availability and accessibility of home energy technologies, there remains a significant information gap regarding their effective utilisation. A survey conducted by Palmer et al. [44] identified a lack of knowledge and guidance among homeowners, preventing them from maximising the benefits of these investments in terms of reducing future energy expenses. Therefore, there is an opportunity in exploring effective ways to inform and educate house owners on those technologies. This study is driven by the objective of addressing the information gap and supporting house owners in their decision-making process regarding the adoption of clean energy and energy-efficient technologies.

The following research questions were raised to guide the study:

- **What practice can effectively bridge the information gap for house owners in renewable energy and energy-efficient technologies?**

- **How to develop effective explanations within a recommender system that foster trust and facilitate knowledge acquisition, thereby assisting households in making sustainable decisions?**

This thesis seeks to contribute to the HCI community by introducing an energy technology recommender as a new IT artefact, and providing insights into trust, explainability, and opportunities related to the energy technology recommender. Overall, the findings of this thesis hopefully can inform the development of future HCI interventions to address environmental challenges.

Chapter 2

Related work

This section initiates by examining the current landscape of available methodologies and potential resources enabling homeowners to access information regarding energy technologies, their associated benefits, and other relevant data. This examination serves as a driving force behind the creation of an innovative design concept, seeking to address potential limitations inherent in current approaches. In addition, the significance of theoretical frameworks cannot be understated in shaping design concepts and understanding user behaviour within the HCI domain. Constructivism stands as a guiding principle in informing the development of this study. Expanding upon this exploration, the section delves into the domain of recommendation systems. This study aims to underscore the impact of personalised, user-driven recommendation systems, shedding light on their substantial contribution to user learning, trust, and decision-making within the domain of energy technologies and sustainable household practices.

2.1 Current practices and potentials

Currently, homeowners have limited avenues to access information about home energy systems. Individuals seeking such information typically have two options. One is visiting specific technology providers, an alternative approach is through professional home energy assessments. Furthermore, research-based models offer evidence to aid homeowners in making informed decisions regarding home energy systems.

2.1.1 Technology providers

Exploring the official websites of technology providers or visiting nearby stores specialising in energy technologies can indeed provide valuable information about specific technologies. However, this necessitates a prior knowledge of the particular energy technology. Moreover, the information obtained through this approach may be restricted to the specific technology being explored, thus failing to offer a holistic perspective on the overall energy system, as energy technologies often function collaboratively.

2.1.2 Energy audits

Professional home energy assessments, commonly known as home energy audits. These assessments are conducted by experts who visit the house and perform a comprehensive inspection. Following the assessment, these professionals provide recommendations regarding house renovations and advice on suitable energy technologies to optimise energy efficiency.

Germany has a wide network of advisory centers and municipal institutions, totaling around 740, that provide energy advice to private households [20]. These centers offer various services aimed at helping households optimise their energy usage and reduce costs. One prominent example is the Verbraucherzentrale Energieberatung [58], which offers independent energy consultants, including individual energy advice and funding tips. The advice provided by these centers covers various important topics, including saving electricity in households, tips for energy conservation as tenants, guidance on thermal insulation and summer heat protection, advice on proper heating and ventilation practices, insights into renewable energy options, and information on modern heating technologies. Notably, these services are public funded, ensuring affordability for the general public, with consultation fees capped at a maximum of 30 euros. Moreover, low-income households can access these services free of charge. Furthermore, some advisory centers also provide online consultations for an initial assessment and to address specific energy-related inquiries. However, the primary focus of these services remains on providing in-person, on-spot consultations.

2.1.3 PVGIS online tool

PVGIS [15] is a web-based application by the European Commission's Joint Research Centre, that enables users to access comprehensive data regarding solar radiation and the energy production of PV systems. This service encompasses a wide range of geographical regions, including Europe, Africa, substantial portions of Asia, and America. Which can be of a great help to house owners when deciding an investment in a PV system.

As shown in the Figure 2.1, the interactive tool allows users to navigate through the map and obtain information regarding performance of grid-connected PV based on the selected location. The visualisation of monthly energy output provides a clear and descriptive representation of the energy generated by a PV system throughout a year. Additionally, the outcome offers highly precise and specialised data, including detailed parameters such as yearly in-plane irradiation and year-to-year variability as well. While this information is highly valuable for researchers, it may pose comprehension challenges for homeowners lacking expertise in the field, thereby hindering their learning process. Furthermore, the data provided is only PV related, lacking the connection to the specific circumstances of individual households.

2.1.4 FLEX models

The FLEX models [61], developed under the newTRENDs project[1] by the Fraunhofer Institute for Systems and Innovation Research, aim to improve the building modeling suite and to analyse the societal trends of prosumaging and energy communities, are capable of calculating the energy demand of buildings at an hourly resolution, while considering the impact of household behaviour, PV generation, and energy storage (thermal and battery) on energy consumption. These models were developed to offer evidence-based information to decision-makers in industry, government, and civil society.

The models take various factors into account, including weather condition, household behaviours and energy technologies, as illustrated in Figure 2.2. Consequently, it offers a comprehensive evaluation of the energy consumption of a building. Moreover, the tool can be used

[1] https://newtrends2020.eu/

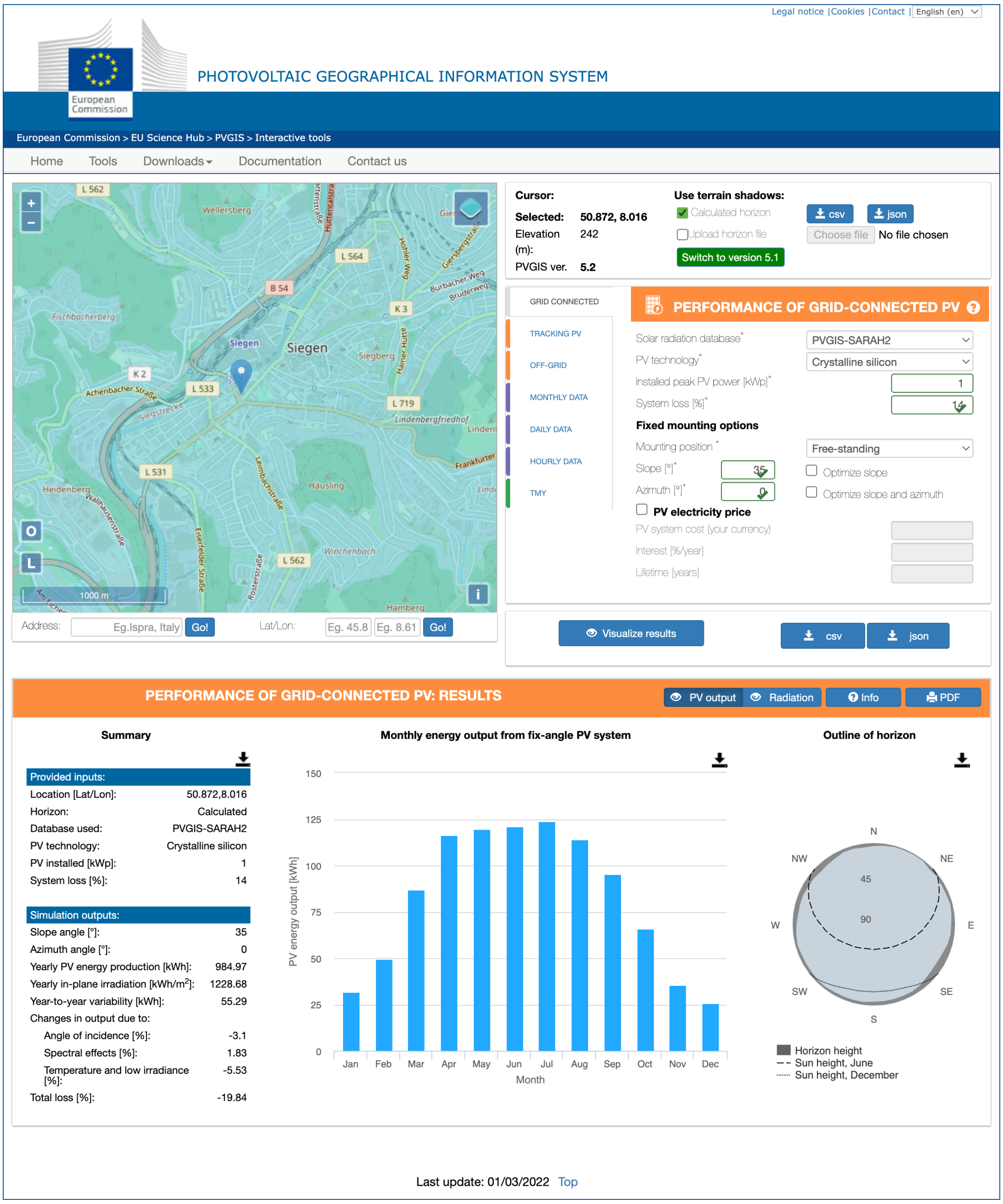

Figure 2.1: Screen of PVGIS online tool

to predict energy bills, enabling comparisons of energy expenses associated with different technology adoptions.

It is important to note that the FLEX models are designed to estimate for single building structures, meaning buildings that do not share walls with other buildings. Furthermore, the FLEX models are implemented in Python. To execute these models, users would need to have Python installed on their systems. Additionally, since the FLEX models involve complex

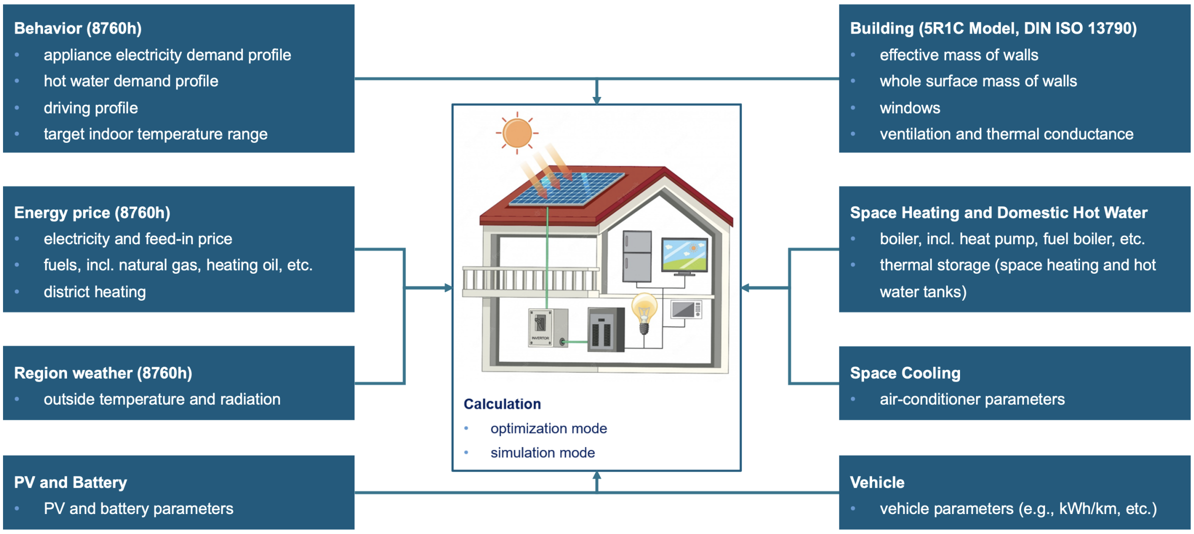

Figure 2.2: Model structure for individual households

optimisation problems, a solver is required. Users would need to download and set up the appropriate solver to run the FLEX models effectively. Moreover, the outputs generated by the FLEX models are in the form of SQL files, which might not be immediately interpretable to non-technical users.

2.2 Relevant theories

The understanding of energy technologies and their implications in domestic settings can be regarded as a form of knowledge claims [6]. Given this, the process of obtaining this knowledge can be likened to a learning journey. To enhance the dissemination of this knowledge to homeowners, learning theories are integrated into the design concept.

2.2.1 Constructivism

Constructivism, a psychological learning theory, delineates how individuals acquire knowledge and learn. It regards the learner as an active participant in knowledge assimilation. This theory emphasises that individuals construct knowledge and meaning from their experiences. It advocates for an approach to teaching and learning where cognition (learning) is the result of ”mental construction”, in essence, students learn by connecting new information to their existing knowledge [3].

The integration of constructivist concepts aims to bridge the information gap by tailoring personalised recommendations to the unique contexts of individual households. These theoretical frameworks propose that users are more inclined to grasp information about technologies and their advantages when they can relate the knowledge to their specific home energy systems. By aligning information with their unique situations, users are more likely to engage and retain knowledge due to the contextual relevance of the recommendations.

2.3 Transition to recommendation systems

Recommender systems (RS) are software tools and techniques designed to provide users with suggestions for items that might be of interest, assisting in various decision-making processes [46]. RSs primarily target individuals who may lack the personal experience or expertise to evaluate an extensive range of alternatives [46]. In the context of homeowners seeking insights into energy technologies, RS becomes particularly valuable, aiding those who are not well-versed in this domain to navigate the vast array of available options.

Building upon Constructivist theories of learning [3], this study emphasises a user-centric approach, aiming to bridge the information gap for homeowners. Incorporating the learning theory, the focus is on linking new knowledge to existing experiences. Through RS integration, users can merge the new knowledge of energy technologies with their present home energy systems, enabling a more comprehensive understanding and fostering a contextualised learning process. Integrating RS into the design concept aligns with the principles of Constructivism, as it empowers users by enabling them to construct their understanding by associating new energy technology knowledge with their current home systems.

RSs have a variety of properties that may affect user experience, such as accuracy, robustness, scalability, and so forth [49]. However, in this study, our primary focus lies on the aspect of trustworthiness, recognised as an important consideration in RS design [42].

Drawing from Kirsten Swearingen and Rashmi Sinha's research [54], specific recommendations are suggested to cultivate trust within a recommendation system. Their proposed measures aim to promote trust by: *ensuring transparent system logic; suggesting novel items; offering* *comprehensive information about recommended items; and enabling users to refine their recommendations by specifying preferred or excluded genres.*

In summary, the integration of RS within the design concept stands as an attempt to bridge the information gap by combining theoretical learning frameworks with a personalised recommendation system. This aims to enhance user learning experiences and foster more informed decisions regarding sustainable energy technologies for households.

2.4 Sustainable energy systems

The pursuit of sustainable energy systems is integral to addressing the urgent challenges posed by climate change and fostering environmentally responsible societies. At its core, the concept hinges on three key activities outlined by Matias et al. [8]:

1. **Increased use of renewable energy sources:** A fundamental step involves a substantial shift towards incorporating renewable energy sources into the overall energy mix. This includes harnessing energy from environmentally friendly sources such as solar, wind, hydro, and geothermal.

2. **Enhanced energy efficiency:** Energy efficiency stands as a cornerstone policy, emphasising the optimisation of energy consumption across various sectors. This involves employing technologies and practices that minimise energy waste while maximising output, contributing to overall sustainability.

3. **Emission reduction:** A critical aspect involves mitigating the emissions of greenhouse gases and air pollutants. Łukasiewicz et al. [62] propose a conceptual model supporting these efforts, offering a framework for in-depth analyses in the pursuit of sustainable energy solutions.

Long-term actions for Sustainable Development (SD) are vital for addressing environmental concerns. Renewable energy (RE) resources emerge as a particularly promising and efficient solution, playing a pivotal role in achieving environmental sustainability [19].

In summary, the realisation of sustainable energy systems necessitates a concerted effort to transition towards renewable energy, optimise energy usage, and curtail harmful emissions, all contributing to the overarching goal of building a sustainable and resilient future.

2.5 Conclusion

Our exploration of the current practices and potentials within the domain of energy technologies and homeowner accessibility to information has revealed a noticeable information gap. Homeowners face limitations in obtaining comprehensive insights into energy technologies and their potential benefits. The current approach, energy audits, can be quite laborious, involving booking appointments with experts, conducting house inspections, and investing considerable time in the assessment process. While government financial support might make the audits affordable, the effort required can discourage homeowners from seeking information and exploring energy-efficient options for their homes.

On the other hand, research-based models, particularly the FLEX models, are powerful tools that offer valuable insights through their detailed data and precise estimations of energy consumption and associated energy bills. These models consider various factors, including the house's characteristics, location, and energy technologies configuration. However, running these models demands professional knowledge, making them less accessible to general homeowners. This creates an opportunity for the development of an innovative IT artefact that could revolutionise the way homeowners access information about energy technologies.

The foundational principles of constructivism demonstrate the importance of contextual relevance in understanding and retaining knowledge. These theories underpin the approach of personalising recommendations to individual home situations. This artefact aims to empower homeowners with easy access to information, enhancing their understanding and fostering informed decisions regarding sustainable energy technologies for their homes.

Chapter 3

Methodology

The study adopts Design Case Studies [60] as the research framework, with a specific emphasis on Grounded Design [53].

In the pre-study phase, our primary objective was to investigate existing practices and tools conducive to homeowners acquiring knowledge about renewable energy and energy-efficient technologies, including their benefits. To achieve this, we conducted comprehensive online searches and reviewed relevant literature. Despite limited successful initiatives in the market, we identified two pertinent options: energy audits and research models. Both were scrutinized to discern effective methods for supporting homeowners in comprehending renewable energy and energy-efficient technologies, along with their associated benefits.

Subsequent to the pre-study, a suitable approach aligned with learning theory was identified, leading to the development of an innovative design concept: a personalised home energy system recommender. To ensure its efficacy, we investigated homeowners' motivations for investing in energy technologies through existing literature. Our focus then shifted to providing recommendations that align with user needs, with a particular emphasis on enhancing the explainability of the system.

Throughout the IT artefact design process, multiple considerations were factored in, including usability, user experience, and the chosen medium. Additionally, five formative evaluations were conducted on high-fidelity wireframes, aiding in the identification of issues that were subsequently addressed through design iterations.

Once the service was programmed and made available online, a summative investigation was conducted to assess the appropriation of the artefact, with specific emphasis on two aspects:

1. **Knowledge Enhancement:** Do users augment their knowledge about energy technologies and the advantages of their adoption through the service?

2. **Trust in Recommendations:** Do users have trust in the recommendations provided by the system?

Six qualitative evaluations were performed with seven actual homeowners. These evaluations took the form of semi-structured interviews, each lasting approximately one to three hours.

Following the evaluations, a thematic analysis was conducted to delve deeper into users' experiences and perceptions. This analysis yielded valuable feedback and insights, serving as a foundation for the next design iteration and allowing for continuous improvements and enhancements to the artefact.

Chapter 4

Design

To bridge the information gap regarding home energy systems, this project aims to provide households with comprehensive knowledge of available technologies in the market. To avoid overwhelming homeowners with excessive information and inspired by the concept of energy audits found during the pre-study, the study proposes a home energy system recommender. This recommender will tailor its recommendations to each household's unique situation, suggesting technologies that align with the needs of house owners.

Constructivism suggests that individuals learn new knowledge by connecting it with existing knowledge and experiences, as this helps to create a framework for understanding and retention of the new information. Therefore, by focusing on personalised recommendations, the study hypothesises that households may be more receptive to learning about the technologies and their benefits. Meanwhile, nudging them towards making informed decisions.

4.1 Motivators for investment decisions

The attitudes and perspectives of users regarding energy efficiency, were investigated through a comprehensive survey conducted by Palmer et al. [44] in the United States. The survey revealed various motivating factors that influence homeowners in their decision to investments in improving energy efficiency. Notably, saving money on utility bills (72%) emerged as the primary motivator, closely followed by the low costs associated with improvements (66%). These findings suggest that homeowners prioritise the financial aspects of energy efficiency when making investment decisions. Surprisingly, preferences related to environmental sustainability ("Green") and the potential increase in property values do not appear to significantly influence their decisions.

From the pre-study, we discovered that the FLEX models hold immense potential as an ideal tool to aid homeowners in making decisions about their energy technology investments. These models incorporate a wide range of factors and consider the entire energy system, this enables them to make relatively accurate predictions of energy consumption and associated energy bills. As we learned from the survey, the financial aspect is a primary consideration for homeowners, and the FLEX models can provide detailed financial insights, empowering them to make well-informed decisions regarding their house situations. The proposed recommender will use the FLEX models to propose technology configurations that can potentially result in energy cost savings for homeowners. For instance, by learning the situation and the current energy system of the house, FLEX models can estimate current energy costs based on assumptions about their energy consumption habits. Subsequently, the models assess the estimated energy costs for various differnt energy systems and identify technology configurations that can potentially lead to cost savings. With the use of these models, homeowners can gain a deeper understanding of the potential outcomes and benefits associated with different energy technology choices, leading to more optimised and cost-effective decisions for their homes.

4.2 Design concept: The home energy system recommender

The home energy system recommender is a software application that integrates the FLEX models, offering personalised recommendations to households based on their individual circumstances. Through the recommended technology configurations and estimated energy costs, users will not only be guided on these technologies but also be educated on the potential benefits of transitioning to more sustainable energy systems. Additionally, the current version of the recommender is limited to single-family houses, as the FLEX models are not yet designed to estimate energy consumption for buildings that share walls with other structures.

The personalised home energy system recommender, therefore, serves as the answer to the first research question of the study.

4.3 Input to the recommender

4.3.1 Household profiles

The concept of household profile has been developed to generate information about the energy demand and supply dynamics of households. To ensure the accuracy of this profile, thereby accurately anticipate household's energy costs, various factors that may impact the household's energy consumption must be considered, 4 categories as shown in Figure 4.1, they are *the external environment, building materials, energy consumption behaviors, and the current home energy system.*

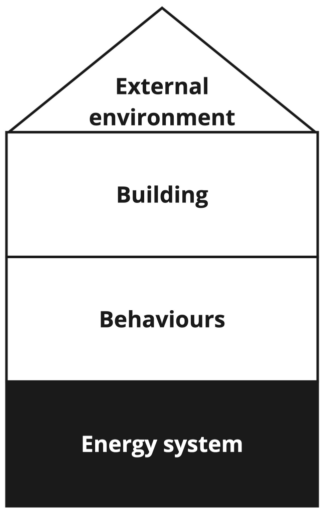

Figure 4.1: Household profile

The categories were inspired by the FLEX models [61]. The models take a set of variables into account when simulating, they can be divided into following 15 categories: *behaviour profile, battery, behaviour, boiler, building, energy price, heating element, hot water tank, PV, region, space cooling technology, space heating tank, vehicle, energy price, region weather.* The specific data required by the FLEX models within each category can be found in Appendix A.

4.3.2 Households data collection

To achieve a balance between accuracy and user-friendliness in the FLEX models, we carefully developed a set of 13 questions (as presented in Table 4.1) to collect relevant information for household profiles. These questions were designed to avoid overwhelming users with excessive information requests while still providing sufficient data for accurate simulations. Furthermore, the user's answers to these questions enable the system to infer additional specific information. For instance, by inputting the construction period of the house, the system can assume corresponding details such as building materials and sizes. All of these design decisions were thoroughly discussed with experts, and their analysis and agreement ensured the efficacy of the approach.

Category	**Question**	**Note**
External environment	Where is the house located?	Understanding the location of the house can provide valuable insight into its environmental factors, such as the amount of sunlight it receives.
Building	When was the house built?	Knowing the year a house was built can provide insight into its construction materials, such as the composition of the walls.
	Has the house ever been renovated before?	Renovations can include upgrading insulation, replacing windows with energy-efficient ones, installing high-efficiency HVAC systems, sealing air leaks, etc.
	What has been renovated in the house?	
Behaviour	How many people are living in the house?	
	How often does each adult work from home?	
	Is there any air conditioner in the house?	
	What type of heating energy is used in the house?	
Home energy system	Is there a photovoltaic (PV) system in the House?	A PV system is a system that uses solar panels to convert sunlight into electricity for use in a building.
	What is the size of the PV system?	The average size of a PV system is 5 kilowatt-peak.
	Is there a battery system in the house?	A home battery system is a device that stores energy produced by solar panels or other sources to be used later when needed.
	What is the capacity of the battery?	The average capacity of a home battery system is around 7 kilowatt-hours.
	Is there a smart energy management system (SEMS) in the house?	A SEMS is a technology to optimise energy usage, monitor consumption, and enhance energy efficiency.

Table 4.1: Household profile questions

To enhance user experience, a decision tree approach was implemented, enabling users to navigate through the questionnaire without the obligation to answer all questions. As a result, the number of questions to be answered ranges from a maximum of 13 to a minimum of 10, as depicted in Figure 4.2.

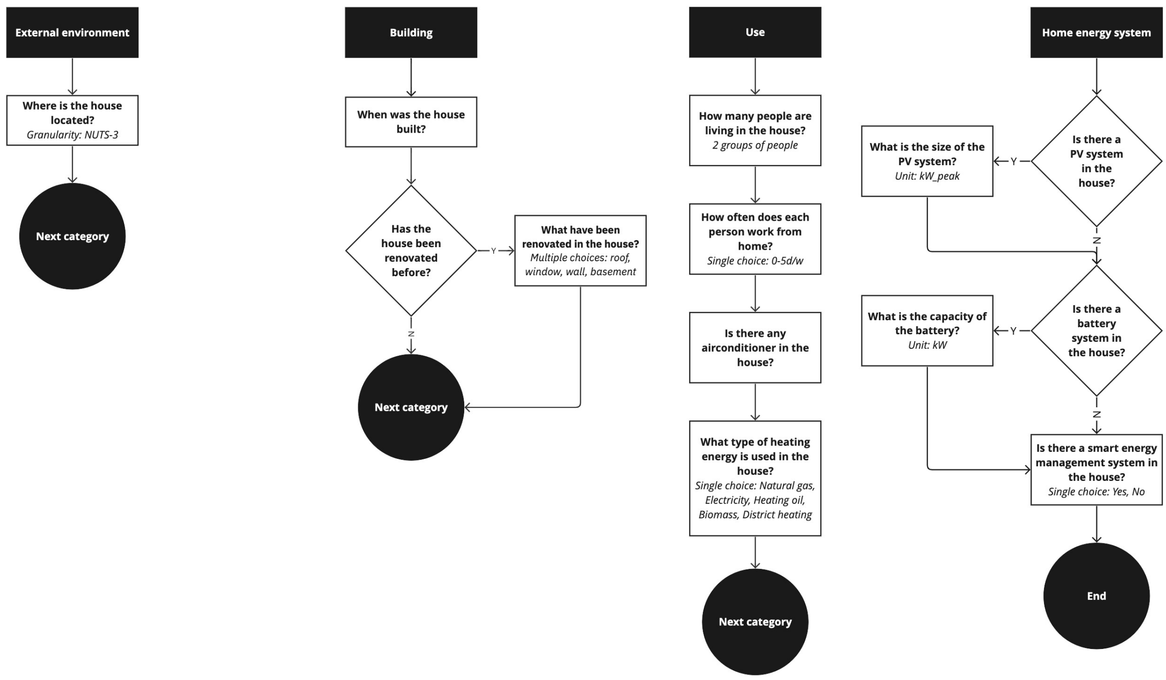

Figure 4.2: Order of household profile questions

4.4 Output from the recommender

4.4.1 Recommendations

A sustainable home energy system should prioritise *energy-efficiency, reducing dependence on non-renewable fossil fuels, and lowering overall energy costs*. All the recommendations provided by our system align with these fundamental principles. Our main objective is to promote sustainable energy practices, with a particular focus on helping users reduce their household energy costs. For instance, if a user does not have a cooling system in place, the system would not suggest installing an air conditioner, as it may impact the energy bill and is considered an unsustainable act. The recommended energy technologies encompass various solutions for generating renewable energy, managing energy usage, and improving overall energy efficiency. An overview of the recommended technologies and their functionalities can be found in Table 4.2.

Recommendation rules

The recommendation generation process follows a rule-based approach. By employing the FLEX models, the system identifies configurations that can lead to lower energy bills compared to the user's current situation. However, to prevent overwhelming users with an excessive number of recommendations resulting from the various combinations of technologies, particularly when accounting for different sizes, we focus on three distinct perspectives related to financial aspects for the recommendations, see Figure 4.3.

Cost-benefit The first perspective is the most techno-economic solution, which compares the annualised investment costs with the annual energy cost to determine the configuration that offers the highest financial advantage for households. This approach takes into account the financial feasibility of implementing the recommended technologies.

Save the most The second perspective focuses solely on the energy bill savings, disregarding investment costs. We offer this recommendation because investment costs may vary across different areas, and users may find cheaper options for implementing the recommended technologies. This perspective also allows users to gain insights into the most energy-efficient configurations available for their homes.

Lowest investment The third perspective is the solution with the lowest investment cost, enabling users to identify a cost-effective first step towards enhancing their home energy system.

In addition, we provide users with the flexibility to customise the energy system according to their specific needs and preferences for those recommendations. This customisation option

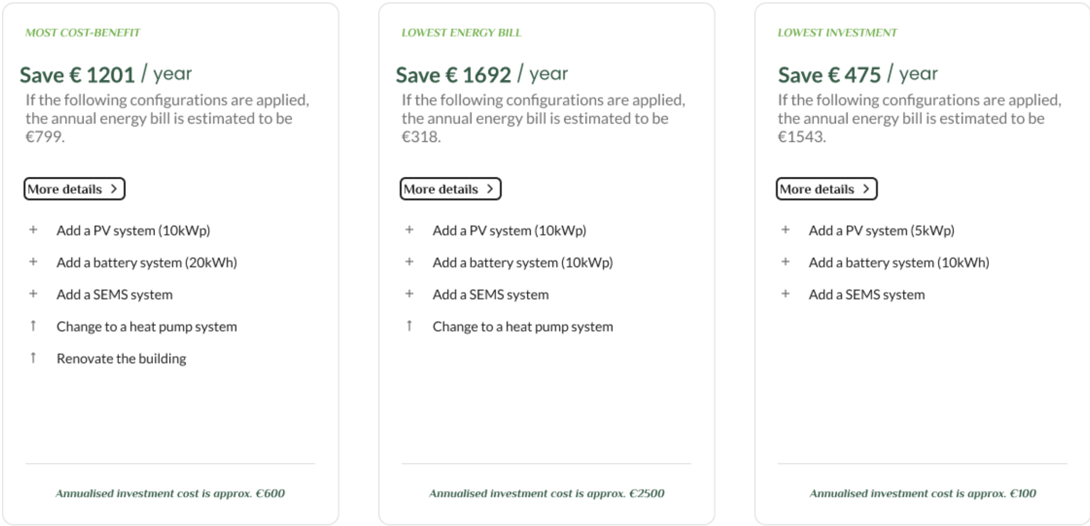

Figure 4.3: 3 categories of recommendations

allows users to see changes in corresponding configurations based on their preferences. This feature also enables trust among users in the system and will be further explained in the explainability section later. We believe that presenting recommendations from three perspectives while allowing customisation strikes an appropriate balance, offering users a tailored and manageable set of options to make informed decisions about their home energy system.

4.4.2 Explainability

Explainability plays a crucial role in establishing trust among users in Recommendation Systems (RS), and this principle holds true for our system as well. When the system generates recommendations for users, it is important for users to understand why a particular configuration is being recommended to them. Explanations aim to bridge this gap by shedding light on the factors that contribute to the recommendation and how they align with the user's preferences (the financial aspect specifically).

Explanation

According to Nunes and Jannach [41], previous studies have identified ten purposes of explanations, including *transparency, effectiveness, trust, prersuasiveness, satisfaction, education,* *scrutability, efficiency, debugging*. In our case, the explanations provided by the system are intended to serve three purposes: *effectiveness, trust, and education*.

Effectiveness The system aims to support users in making informed decisions by providing the corresponding yearly energy bill. As they can immediately gauge the financial implications and potential cost savings associated with each recommendation. (Figure 4.4)

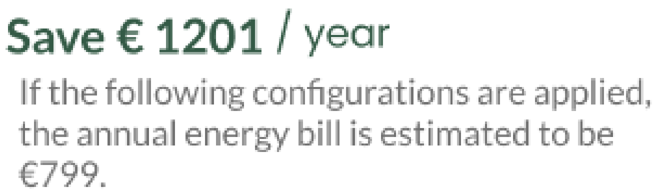

Figure 4.4: Effectiveness

Trust By offering more detailed estimated energy consumption patterns, users gain a deeper understanding of how the energy bills are calculated in the recommended configurations, thereby building trust and confidence in the accuracy and reliability of the system's outcomes. (Figure 4.5)

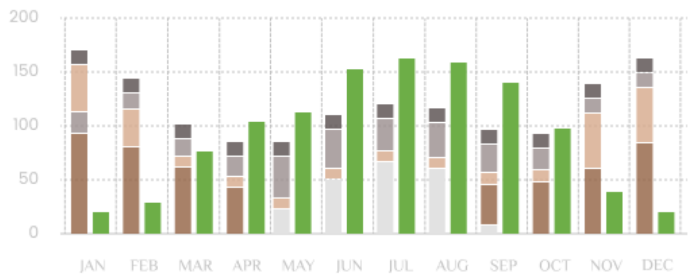

Figure 4.5: Trust

Education The system utilises explanations as educational tools to offer users valuable insights into the recommended technologies and their impact on energy bills, furthermore, the system can also provide information about the broader context of climate change, helping users understand the larger picture and the importance of sustainable energy practices.

Exploration

Beside retrospective explanations, prospective user interfaces can play a significant role in guiding users incrementally toward their goals and enhancing user control and transparency in the recommendation process. According to a study by Siepmann and Chatti [50], such interfaces have the potential to facilitate the development of a more accurate mental model of the decision-making system. Therefore, in our design, by providing interactive and visual interfaces, users are empowered to actively explore and adjust various configurations of the recommended technologies (Figure 4.6). This level of control allows users to observe and analyse the corresponding simulated results in real-time. As users manipulate the configurations, they gain a better understanding of how changes impact the outcomes. By making the system's workings visible and allowing users to actively participate, users can develop a clearer mental model of how the system functions and how different choices influence the results. This transparency and user empowerment contribute to increased trust and understanding of the decision-making system.

Levels of explanations

In addition, a study conducted by Kim et al. [36] examined the explainability needs of 20 diverse end-users and revealed that the level of explainability required varied based on participants' backgrounds in AI and their interests in the domain. While there was a general curiosity about AI among participants, only those with a high level of AI expertise or a significant interest in the domain expressed a need for detailed explanations regarding the RS system. Therefore, it is essential to provide different levels of explanations to accommodate the varying characteristics of users and meet their specific needs.

The first level of explanation For users who are primarily focused on improving their home energy systems without a deep interest in understanding the underlying system, this level of explanation presents the recommended configurations, specifying financial information on the corresponding yearly energy bills, and the bills saved associated with each configuration and the investment costs. The objective is to ensure that users comprehend the potential benefits of implementing the recommendations. By clearly presenting the recommended configurations and their associated energy bills, users can readily evaluate

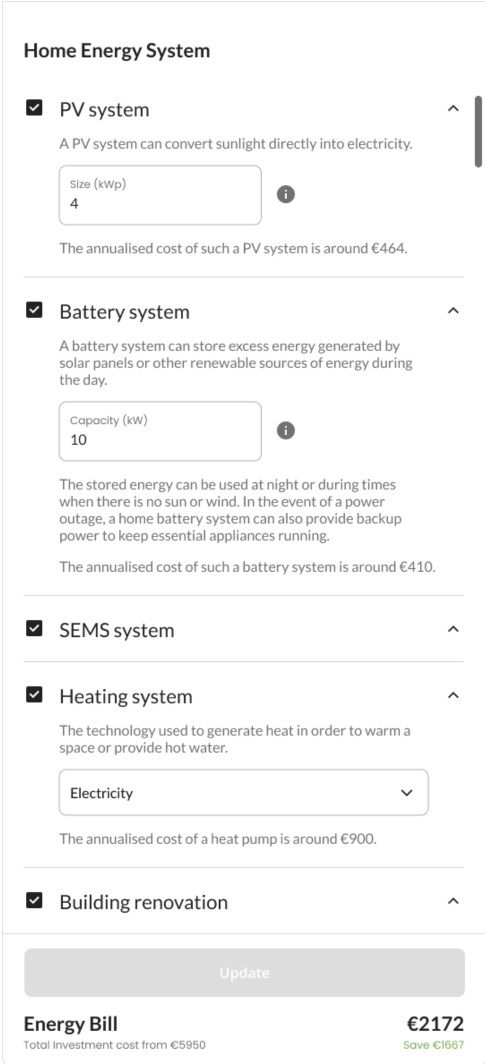

Figure 4.6: Exploration

the potential improvements that can be achieved in terms of energy efficiency and cost savings. (Figure 4.7)

The second level of explanation For users who have doubts about the recommendations and possess a curiosity about how the system operates, besides the first level information, this level of explanation offers insights through generated energy consumption patterns and encourages user exploration to understand the underlying workings of the system. They can observe how different configurations or technology choices impact energy consumption and ultimately influence the calculation of yearly energy bills. By facilitating user interaction and transparency, the system aims to build trust and alleviate doubts, enhancing user confidence in the system's recommendations. (Figure 4.8)

The third level of explanation This level of explanation focuses on providing cognitive knowl-

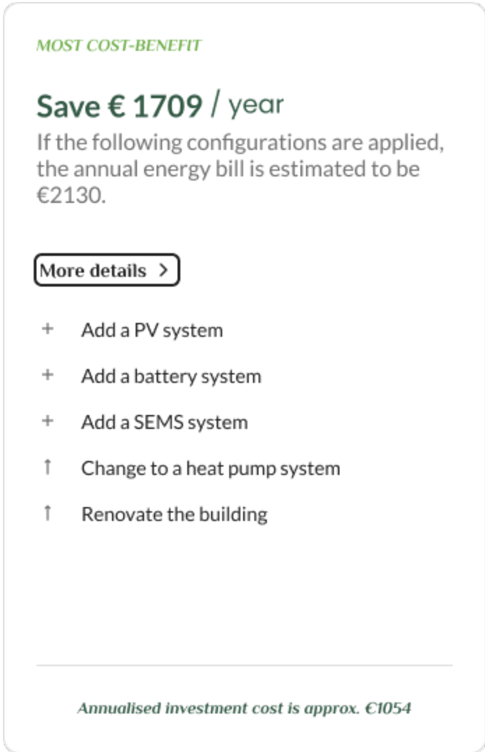

Figure 4.7: First level of explanation

edge to users. It goes beyond the technical aspects of the system and delves into the broader context of environmental protection and sustainability. Users are encouraged to consider the long-term consequences of their energy-related decisions and their role in contributing to a more sustainable future. It aims to raise awareness among users, foster a sense of responsibility, and offer additional information and resources for embracing sustainable practices beyond the immediate recommendations of the system. (Figure 4.9)

Additional information

In addition to the aforementioned, there are several other techniques that are considered to further support users in their decision-making process. These techniques aim to provide additional information to enhance user understanding, facilitate comparisons, and enable informed choices.

Comparison with current situation To ensure users can verify the accuracy of our system, we provide a valuable reference point by offering simulated versions of their current energy bill and consumption. This feature allows users to compare the system's simulations

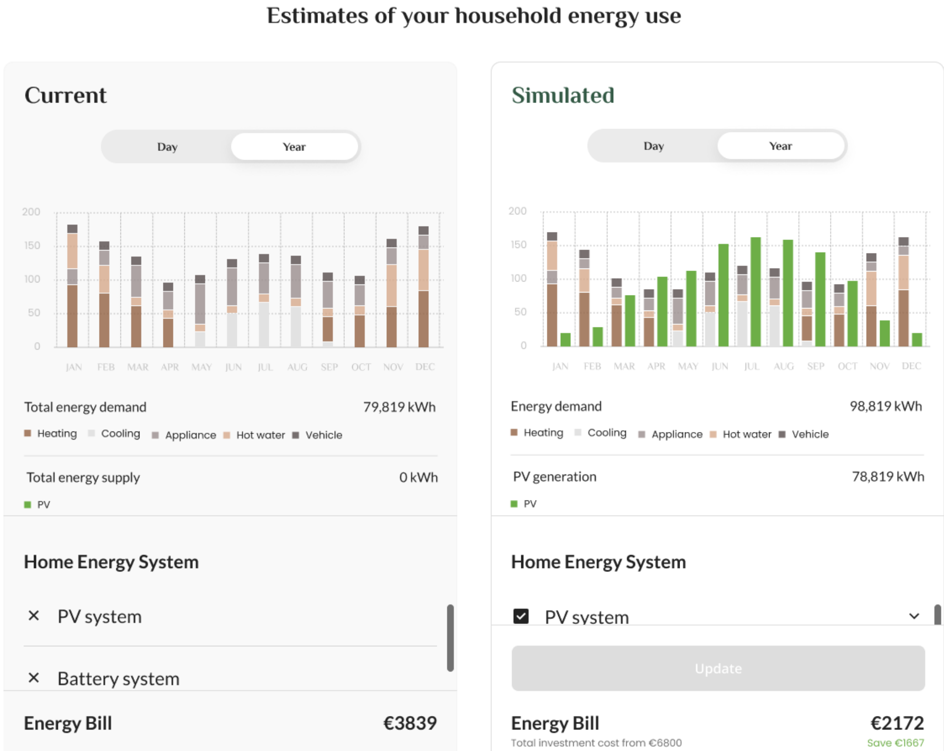

Figure 4.8: Second level of explanation

with their actual energy usage, enabling them to assess the reliability and accuracy of the recommendations. By presenting users with their simulated current energy bill and consumption, they can directly observe how closely the system's simulations align with their real-life data. This serves as a tangible measure of the system's effectiveness and enhances user confidence in its recommendations. The verification process not only fosters user trust and confidence but also allows us to collect valuable user feedback for continuous improvement. By actively seeking user perspectives and incorporating their feedback, we can refine the algorithms and models, ensuring that the recommendation system evolves and remains responsive to users.

Technology explanation a brief explanation (Table 4.2) of each recommended technology is provided to help users understand their functionalities and how they contribute to energy efficiency. The technology introductions are presented in a clear and straightforward manner, avoiding technical jargon and using language that is easily understandable for users with varying levels of knowledge about energy systems. This ensures that users can quickly grasp the main concepts and functionalities of each technology without feeling

Have you noticed an increase in the frequency of news about natural disasters triggered by severe weather?

What is global warming?

Global warming refers to the long-term rise in earth's average surface temperature, which is largely attributed to the increasing concentration of greenhouse gases in the atmosphere. These gases, including carbon dioxide, methane, and nitrous oxide, trap heat from the sun and prevent it from escaping back into space, leading to a gradual warming of the planet.

What are the causes of global warming?

Human activities are the primary cause of global warming, particularly the burning of fossil fuels like coal, oil, and natural gas for energy. Deforestation, agriculture, and industrial processes also contribute to greenhouse gas emissions.

What damages have caused by global warming?

Global warming has a range of negative impacts on the environment, including rising sea levels, more frequent and severe heat waves, droughts, floods, and storms, and the loss of biodiversity. These changes can lead to the displacement of human populations, food and water scarcity, and increased risks to public health.

What is the goal to address global warming?

The EU has set a target of reducing greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels, and reaching net-zero emissions by 2050. To achieve this goal, EU countries are implementing a range of policies and measures to promote energy efficiency and renewable energy.

How to prevent or slow down global warming as citizens and consumers?

As citizens and consumers, there are many actions that we can take to help prevent or slow down global warming. Here are some key ways that you can make a difference:

Reduce energy use: One of the biggest contributors to greenhouse gas emissions is the energy we use in our daily lives, from heating and cooling our homes to driving our cars. To reduce your energy use, consider:

- Turning off lights and electronics when not in use
- Using energy-efficient appliances and light bulbs
- Lowering your thermostat in the winter and raising it in the summer
- Walking, biking, or taking public transit instead of driving
- Carpooling or using ride-sharing services when possible
- Investing in an electric or hybrid vehicle

Conserve water: Another important way to reduce your carbon footprint is to conserve water. This can be done by:

- Fixing leaky faucets and pipes
- Using low-flow showerheads and toilets
- Watering your lawn and garden less frequently
- Collecting rainwater for outdoor use
- Only running the dishwasher and washing machine when they are full

Reduce waste: Landfills are a major source of methane, a potent greenhouse gas. To reduce your waste, consider:

- Recycling and composting as much as possible
- Using reusable bags, water bottles, and containers instead of disposable ones
- Buying products with minimal packaging
- Donating or selling unwanted items instead of throwing them away

Support renewable energy: Choosing to support renewable energy sources can help to reduce greenhouse gas emissions and promote a more sustainable energy system. Consider:

- Installing solar panels on your home or property
- Choosing a green energy provider for your electricity
- Supporting policies and regulations that encourage renewable energy development

Advocate for change: As a citizen, you can make a difference by advocating for change at the local, national, and international level. This might include:

- Voting for political leaders who prioritize climate action
- Writing to your elected officials to express your concerns and priorities
- Supporting advocacy groups and organizations that work on climate and environmental issues

By making small changes in our daily lives and advocating for larger systemic change, we can all play a role in creating a more sustainable and resilient future.

Figure 4.9: Third level of explanation

overwhelmed by complex technical details. It empowers users to make more informed decisions by providing them with the necessary knowledge to assess the relevance and suitability of each technology for their specific energy needs and goals.

Technology	**Explanation**
PV system	A PV system can convert sunlight directly into electricity.
Battery system	A battery system can store excess energy generated by solar panels or other renewable sources of energy during the day.
SEMS	A Smart Energy Management System (SEMS) can optimise energy usage by adjusting heating and cooling systems, lighting, and other energy-consuming devices to minimise energy waste; and turning off or reducing energy usage during periods of low occupancy or when energy prices are high.
HP	A heat pump is a device that transfers heat from one place to another, providing both heating and cooling for spaces.
Hot water tank	A hot water tank is a device used to store domestic hot water for use in homes. The hot water in the tank can be used in sinks, showers, or appliances.
Space heating tank	A space heating tank is a device used to store hot water to provide heat to interior spaces in homes.
Building renovation	Building renovation can have a significant impact on improving home energy efficiency performance by reducing the amount of energy needed to heat, cool, and operate a home.

Table 4.2: Brief introduciton of each technology

Investment costs The consideration of supplementary information pertinent to users' investment decisions holds significance. Hence, we endeavor to furnish users with additional information regarding technology costs. However, it is imperative to acknowledge that various brands exhibit divergent pricing structures, and the performance or size variations of individual technologies directly influence their corresponding costs. In light of this, we present users with a range of costs associated with each technology, aiming to facilitate their decision-making process by fostering informed choices. The specific cost ranges are presented in the Table 4.3.

Technology	Initial investment (€)	Life (year)	Annualised cost (€)	Ref
PV system	1200/kWp	15	115.61/kWp	[9]
Battery system	428.57/kWh	15	41.29/kWh	[9]
SEMS	1000	15	96.34	[9]
HP	/	/	900	[10]
Building renovation	/	/	2000	[31] [30]

Table 4.3: Investment costs of different technologies

Presentation

Both Natural language (NL) and Information visualisation (IV) techniques are used to serve different purposes and enhance the overall clarity and effectiveness of conveying information to users. NL explanations, as shown in Figure 4.10, in the form of textual descriptions, are utilised to provide detailed information about technology functionalities and costs.

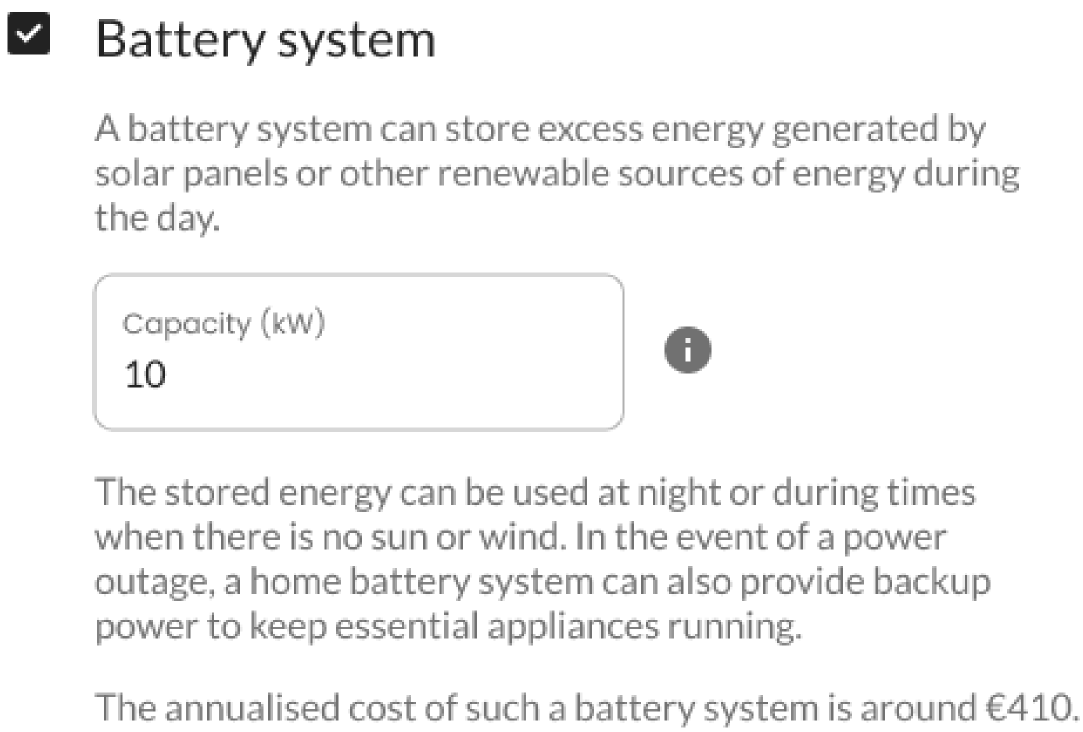

Figure 4.10: NL explanation

Charts are employed to present energy consumption data in a visual format, as shown in Figure 4.11. Visualising energy consumption data of each sector using charts helps to simplify complex information, enabling users to grasp patterns and comparisons more easily. Users can observe the relative contributions of different sectors, identify areas of high or low energy consumption, and explore alternative scenarios or configurations.

4.5 Medium

At present, the service is designed as a one-time interaction where users receive recommendations and may not revisit the system in the near future. Meanwhile, the explanations provided

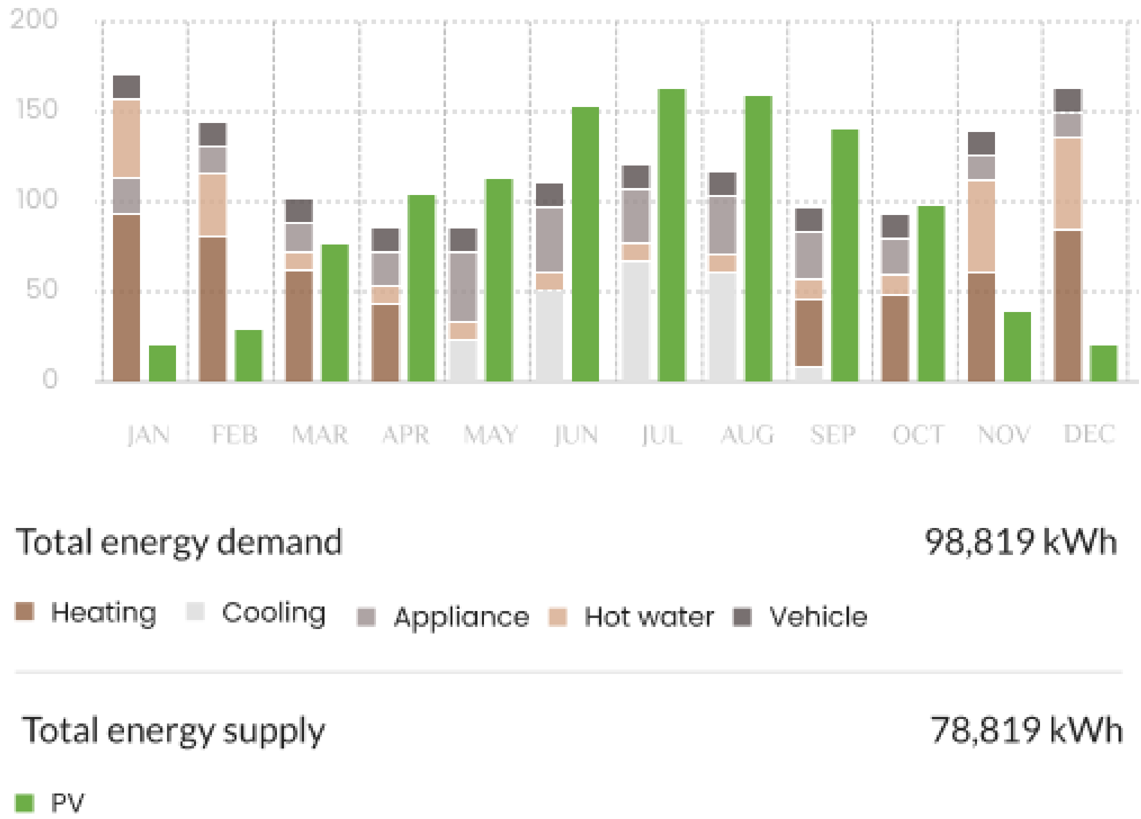

Figure 4.11: IV explanation

can be presented in a highly detailed manner, as users have the opportunity to carefully read and understand the information. The interactive nature of the system allows users to compare complex data and explore different configurations. A larger screen offers a more comfortable viewing experience, therefore, the current focus is on desktop or larger screens. However, considering the prevalent use of smartphones in today's society, it is important to acknowledge the need for a mobile-friendly version of the service.

4.6 Interfaces

In this chapter, several key interfaces are explained, providing an overview of the important pages and features of the system. While not all pages are covered, the focus is on highlighting the interfaces that play a significant role in the user experience and decision-making process.

Homepage

The homepage (Figure 4.12) of the website serves the purpose of informing participants about the functionality and process of the service. Several factors related to usability are considered in the design and content of the home page:

Purpose explaining The homepage should clearly communicate the purpose of the service, highlighting its main objective and benefits for participants, in order to help users understand the core function and value proposition of the website.

Instruction A 2-step instruction is provided to guide users through the process of using the service before they begin, this is to ensure that users are mentally prepared for the service and have a clear roadmap to follow.

Time indicator The estimated time required to complete the questionnaire is provided to users as a feature to mentally prepare them for the task at hand. By indicating the expected time commitment, users can have a better understanding of the anticipated duration of their engagement with the system.

Policy Users are informed about the data handling practices and security measures implemented by the website. Additionally, users also have the opportunity to delve deeper into the specifics of data handling practices by accessing more detailed information. The privacy policy can be found in Appendix B.

Organisations involved The homepage introduces the relevant organisations involved in the development and operation of the service to establish credibility in the reliability and expertise of the system.

Contact details Email addresseses is provided to allow participants to reach out for support, clarification, or any other inquiries they may have.

Language options The service offers language options in both English and German to cater to a broader audience in Europe.

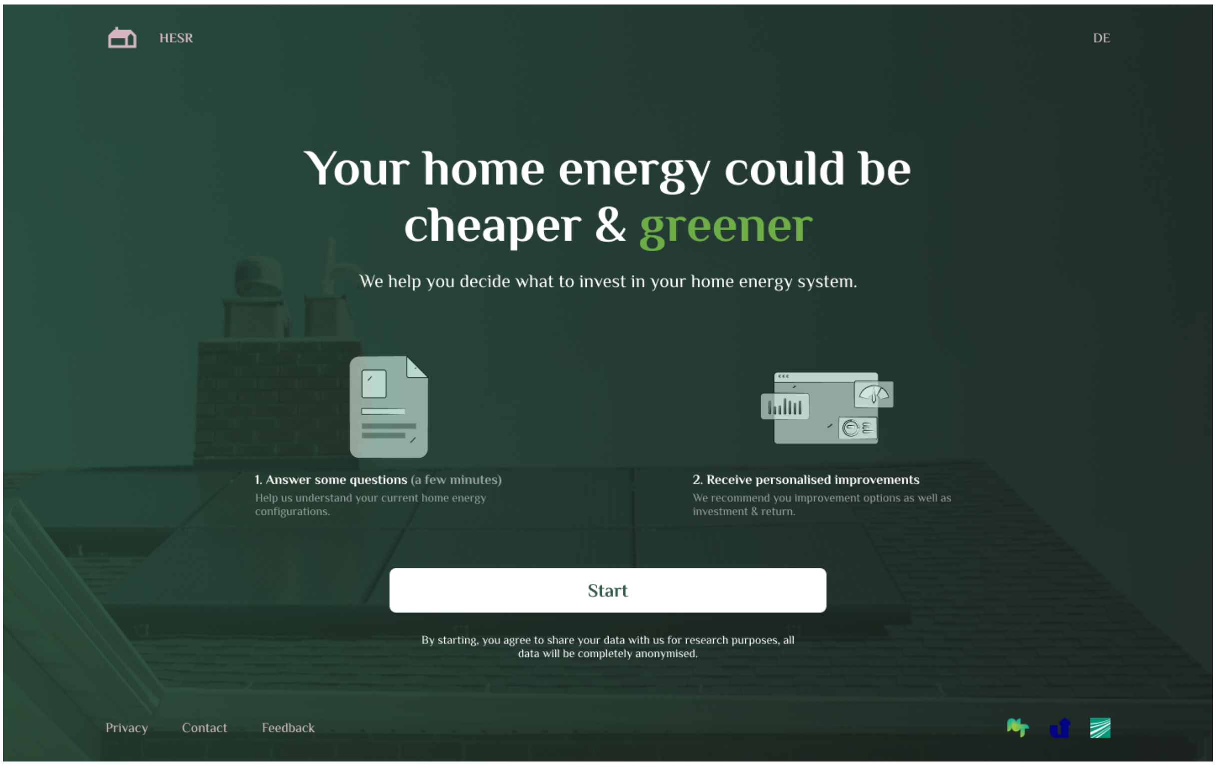

Figure 4.12: Homepage

Questionnaire page

The questionnaire page (Figure 4.13) is specifically designed to collect information pertaining to the household's current energy demand and supply-related factors. Its purpose is to gather comprehensive data in order to construct a detailed household profile. Several usability factors are taken into account to enhance user experience on this page:

Question categorisation Each question is assigned a relevant category to provide context to users.

One question at a time To present one question at a time, ensuring that users understand precisely what information is being requested from them. Users can focus their attention on each individual question without feeling overwhelmed by a large set of inquiries, which allows for better comprehension and reduces the risk of confusion or misunderstanding.

Transparent process The page outlines the overall process, indicating the number of categories involved.

More details For unfamiliar or complex concepts, the page offers more detailed explanations to provide users with a better understanding.

Return and edit The page allows users to easily navigate back to the previous page and make changes if they need to modify their answers.

Figure 4.13: Questionnaire

Recommendation page

The recommendation page (Figure 4.14 and 4.15) serves as a crucial component of the system, aiming to inform users about the available home energy system options that can potentially lower future energy costs and improve energy efficiency. The page provides clear and simple explanations (annual energy costs) behind each recommendation. To ensure usability and meet user needs, the recommendation page incorporates the following features:

List of recommendations The page presents all the recommended options, or in some cases, informs users if no specific recommendation is available.

Estimated current energy bill Users are provided with an estimated current energy bill, allowing them to compare their existing energy costs with the potential savings offered by the recommended options. This provides a tangible reference point for users to assess the financial impact of the recommendations.

First level explanation Each recommended option is accompanied by specific information regarding the potential financial benefits it offers, including money saved and the projected annual energy bills.

Allow for detailed sxplanations For users who seek more in-depth information, the recommendations page offers the option to access more detailed explanations.

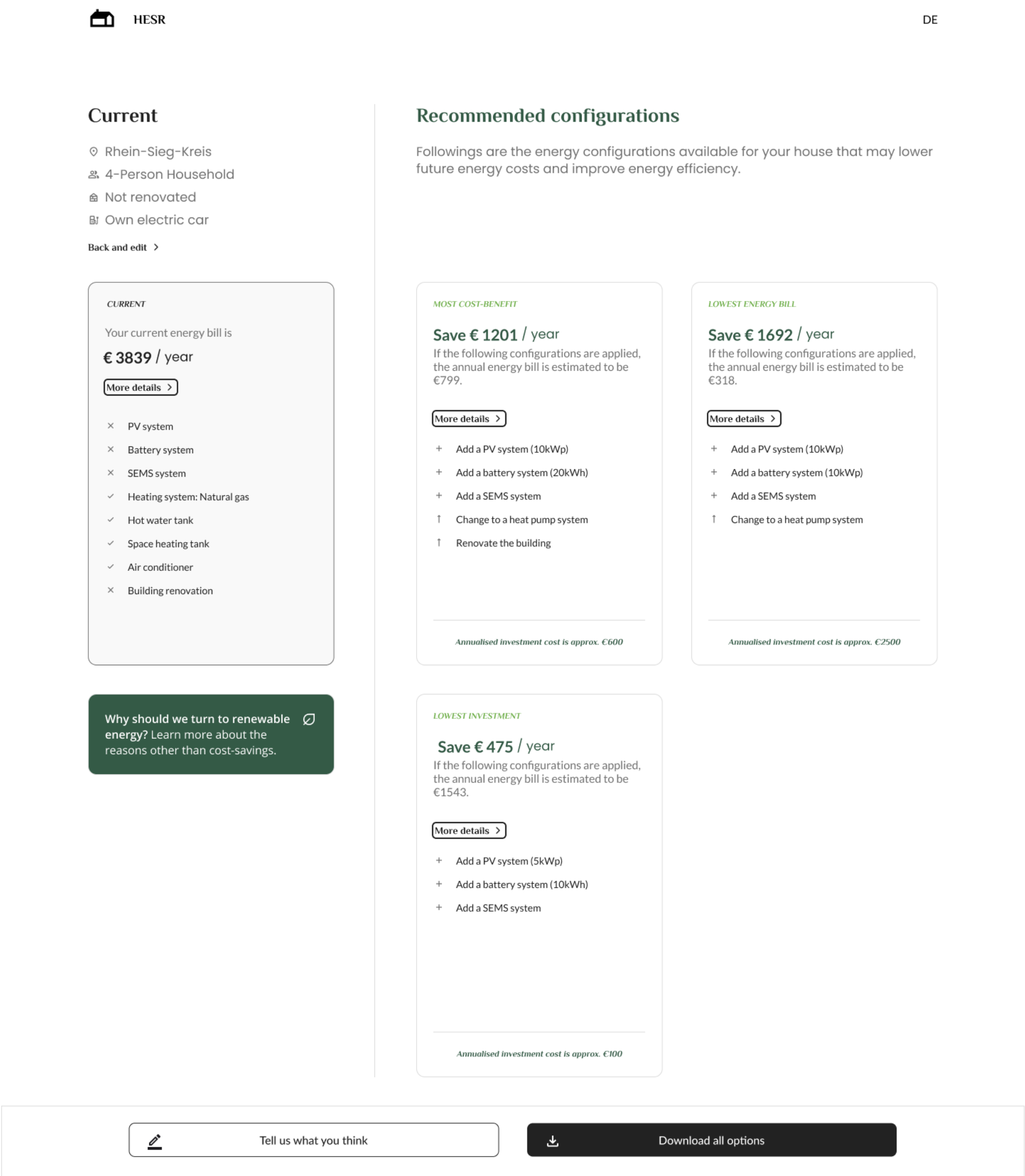

Figure 4.14: With recommendations

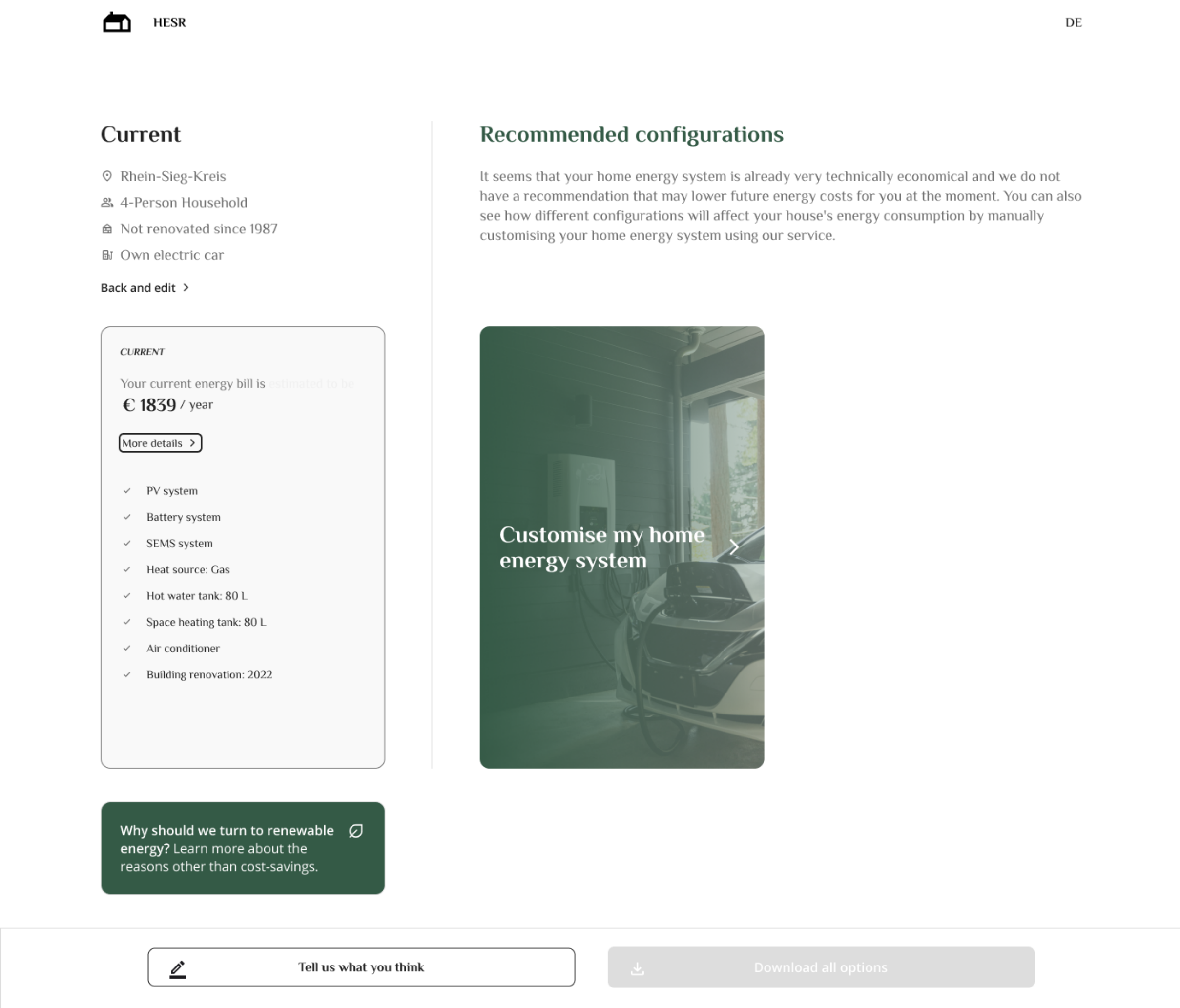

Figure 4.15: No recommendation

Simulation page

The simulation page (4.16) aims to provide users with more detailed explanations about the recommended options.

Data visualisation It utilises data visualisation techniques to present information in a visually engaging and easily understandable format.

Comparison The simulation page allows users to compare the recommended options with their current configuration using visualised data, making it easier to understand the differences in energy consumption and demand. The comparison enhances users' understanding of the disparities between the recommended options and their current configuration, enabling them to assess the potential benefits.

Exploration The simulation page enables users to make adjustments to the recommended options. Users can modify various parameters, such as the system size, or technology configurations, and recalculate the results accordingly. This interactive functionality empowers users to explore different scenarios and understand how their choices affect the projected outcomes.

4.7 Formative evaluation

In the initial phase of evaluation, a formative evaluation session was executed involving 5 participants. This preliminary assessment aimed to evaluate the usability of the service prior to commencing the coding phase. The objective was to ensure that the service meet the usability requirements and to gather initial feedback on the explainability of the recommendations provided.

4.7.1 Participants

The 5 participants selected for the testing session were mainly Human Computer Interaction (HCI) students from Siegen University, chosen through convenient sampling. Because of their background in HCI, they have a solid understanding of usability, which made the evaluation an expert's heuristic evaluation.

4.7.2 Testing content

During the testing session, all participants were asked to interact with an interactive Figma prototype to explore and discover recommendations for "their" home energy systems. Following the prototype interaction, participants were required to complete an online survey created using Typeform [55]. The survey consisted of the following questions:

- What do you think this website is about?
- How clear were the instructions on the website for you to follow?

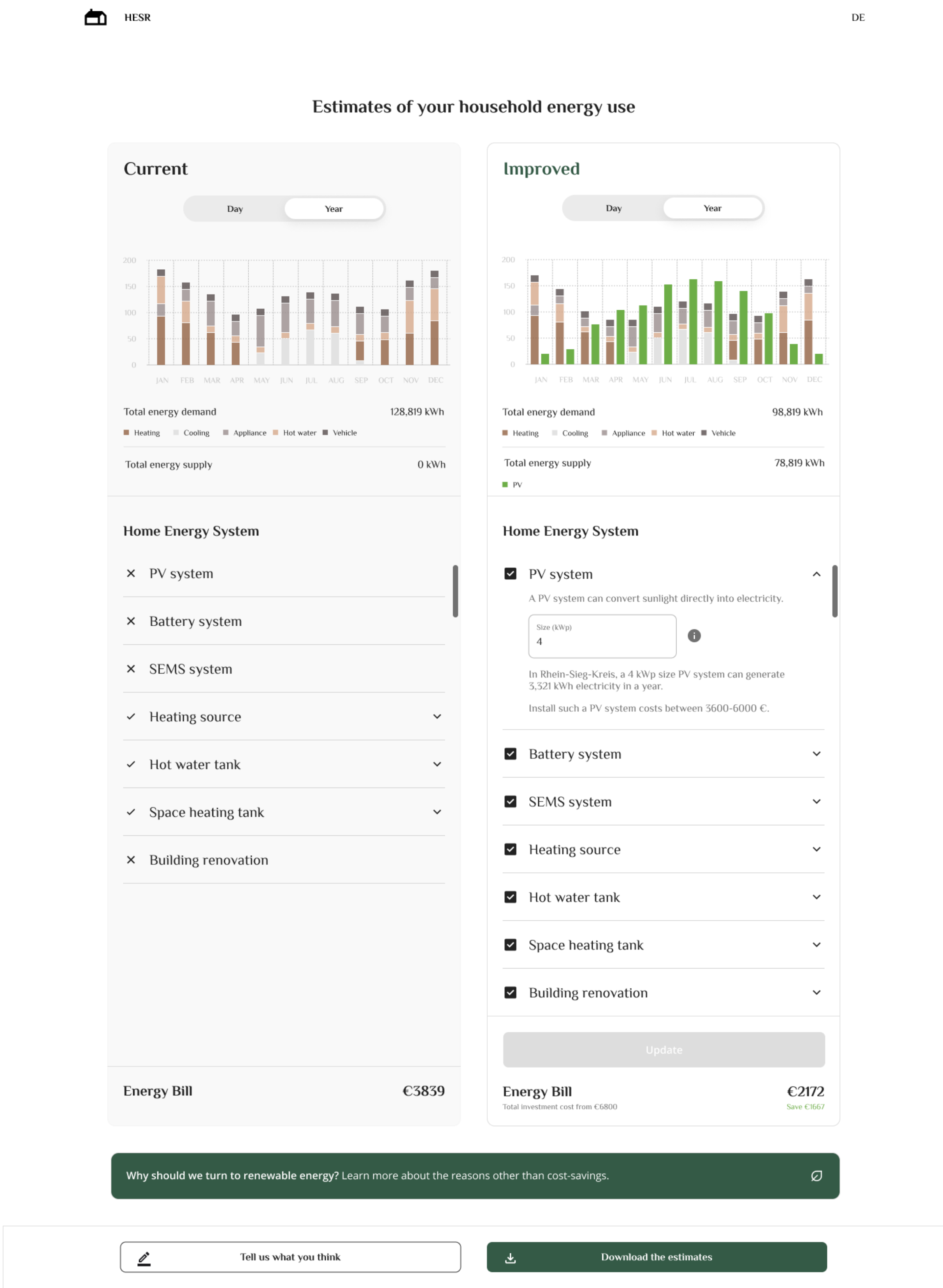

Figure 4.16: Simulation page

- Did you find the website visually appealing?
- Was the website easy to use and understand?
- How long do you think it took you to complete the questions?
- What would you change about the website to make it more user-friendly?
- Were the recommendations easy to understand?
- Was there anything about the recommendations that you found confusing or unclear?

4.7.3 Analysis of formative evaluation

The evaluation of the service involved collecting responses from the participants through a survey (see Appendix C). Overall, the participants demonstrated a good understanding of the website's purpose, which is focused on energy and cost savings in households. However, it should be noted that one participant (Participant 3) provided somewhat unclear answers, and the responses to text-based questions were overly simplistic. Regarding the usability of the website, the majority of participants (4 out of 5) found the instructions to be clear and considered the web interface visually appealing. Additionally, they reported that the website was easy to use and understand, indicating a positive user experience. The participants expressed positive feedback regarding the understandability of the recommendations. Three out of five participants gave high scores of 9/10 or full marks when rating the ease of understanding the recommendations. In terms of the time taken to receive the recommendations, most participants indicated that they spent less than 5 minutes, which aligns with the desired design goal. The feedback provided by the participants also highlighted several areas for improvement and enhancement of the service. The following suggestions were made:

- Allow users to go back to previous questions.
- Provide more assistance to help users find the correct options.
- Use "photovoltaic" instead of "PV" for better clarity.
- Provide more explanations about PV and SEMS to enhance understanding of these terms and their role in the energy system.

- Incorporate a wider variety of selection elements, beyond just clicks, to enhance user interaction.
- Improve the usefulness of the step tracer by indicating the exact number of questions.
- Provide suggested minimal or maximal temperatures instead of having users input an ideal temperature range.
- Include more information about the final investment and the time required to recoup the investment.
- Display corresponding results for different PV sizes to assist users in determining the most suitable size.
- Make the survey questions feel more like a friendly inquiry rather than a formal questionnaire.

4.8 Iteration

After identifying the areas that required improvement based on the feedback, several redesigns were implemented. Firstly, a ”back” button was added to allow users to navigate to previous questions easily. To simplify the options and facilitate decision-making, the number of available choices was reduced, while an indication of the most average option was provided. To enhance understanding, each technology now includes an explanation of its functionality as a helpful hint. Two types of selection elements were introduced: dropdown selection and tab bar selection, providing users with different interaction experiences. Since the exact number of questions to be answered by each participant could not be guaranteed, it was decided to temporarily hide the step tracker. This was done to avoid providing confusing or inaccurate indications. The temperature range question was removed to streamline the survey and make it more user-friendly, as the range is typically common to most people. To facilitate decision-making, annualised costs were presented to help users determine the techno-economic viability of the recommendations. Additionally, calculations were also performed to assist users in identifying the most suitable PV sizes to invest in. Due to time constraints, incorporating more playful elements into the questionnaire was not prioritised. This remains an area for future consideration and further development.

Chapter 5

Development

The web application is designed, with the frontend responsible for collecting user data and presenting recommendations and explanations, while the backend handles the database generated by the FLEX models. The source code [39] is available for access online.

5.1 Frontend

The frontend of the web application is responsible for creating an engaging and user-friendly interface using HTML, CSS, and JavaScript. They were used to structure the content, define the visual styles, and add interactivity to the application. HTML is used to create the structure of the webpages, CSS is employed to style the visual appearance of the application. JavaScript plays a crucial role in adding interactivity and dynamic functionality to the web application. Additionally, JavaScript is responsible for making asynchronous requests to the server, facilitating communication with the backend. To ensure a responsive design, the web application utilises the Bootstrap framework. Although the service is not intended for mobile screens, a responsive user interface that adapts to various devices and screen sizes has been taken into account.

5.1.1 Questionnaire

To incorporate questionnaires into the web application, we integrated SurveyJS, an open-source JavaScript form builder library [11]. SurveyJS simplifies the process of creating and embedding surveys. It supports logic and branching, allowing for dynamic survey behaviour based on user responses, that fulfils our need of presenting corresponding questions according to the answers, as decribed in the design section.

5.1.2 Charts

For chart building, we initially opted for Google Charts, a charting library provided by Google [26]. However, we encountered difficulties in building multiple columns using Google Charts. As a result, we switched to Highcharts [29], another powerful charting library written in JavaScript.

5.2 Backend

The backend of the web application utilises Flask, a Python-based web framework [43], to serve as the intermediary between the frontend and the FLEX models. This choice was made based on the fact that the FLEX models are implemented in Python. Originally, our intention was to enable direct communication between the backend and the models using Python. However, during the development process, we realised that the models' calculations, especially when finding recommended configurations, could be time-consuming. Each scenario takes approximately seven seconds to calculate, and considering the need to identify multiple scenarios that could save energy costs for the household, it would be impractical to make the user wait for the results. To address this issue, we decided to pre-process the data in the FLEX models and store it in a database. This approach significantly reduced the time required to identify energy-saving scenarios, allowing for a more efficient user experience.

5.2.1 API

The API uses the HTTP protocol and follows a RESTful architecture. It provides a set of endpoints that allow users to communicate, via JSON objects, with the recommendation system. The api consists of four endpoint: **scenario**, **recommendation**, **energy_data**, and **energy_cost**. For each endpoint, there is one of two HTTP methods available: **GET** and **POST**.

The following sections describe the endpoints and their properties in more detail.

Scenario

The **scenario** endpoint is used via a **POST** method to send a **scenario configration** to the recommendation system and receive a unique **scenario id** in return. A scenario configuration is a JSON object that describes the house and it's energy system (see table 5.1). The **scenario id** is an integer that uniquely identifies the scenario.

Name	Type	Description	Optional
battery	object	JSON object describing the installed battery	Yes
building	object	JSON object describing the building	No
pv	object	JSON object describing the installed PV	Yes
boiler	object	JSON object describing the installed boiler	Yes
region	object	JSON object describing the region	No

Table 5.1: Scenario configuration

Recommendation

By sending a **GET** request to the **recommendation** endpoint with a **scenario id** as a parameter, the user can retrieve a list of recommended configurations and their associated costs. The schema of an entry in the list is described in table 5.2.

Energy data

The energy_data property contains data related to energy demand and PV generation (See table 5.3). By sending a **GET** request to the **energy_data** endpoint with a **scenario id** as a parameter, the user can retrieve the energy_data for the scenario.

Name	Type	Description
config	object	A scenario configuration as described in table 5.1.
type	string	Recommendation type. Can be either "Lowest Energy Bill", "Lowest Investment", "Cost Benefit".
yearly_bill	integer	The yearly energy bill for the recommended configuration.
investment_cost	integer	The annualised investment cost for the recommended configuration.

Table 5.2: Recommendation entry

Name	Type	Description
total_demand	integer	The total energy demand in a year.
total_generate	integer	The total energy generated by PV in a year.
boiler	array	The energy demanded for heating in the house for each month.
cooling	array	The energy demanded for cooling in the house for each month.
appliance	array	The energy demanded by all appliances in the house for each month.
hotwater	array	The energy demanded for hot water in the house for each month.
pv	integer	The energy generated from PV in the house for each month.

Table 5.3: Properties of energy_data

Energy cost

The energy_cost property contains data related to energy cost (See table 5.4) and can be retrieved by sending a **GET** request to the **energy_cost** endpoint with a **scenario id** as a parameter.

Name	Type	Description
yearly_bill	integer	The total energy cost in a year.

Table 5.4: Properties of energy_cost

5.2.2 Usage

A user can interact with the API by sending HTTP requests to the endpoints described above. The usual workflow is as follows:

In the initial step the user sends a **POST** request to the **scenario** endpoint with a **scenario configuration** as a parameter and receives a **scenario id** in return. Then, the user sends a **GET** request to the **recommendation**, **energy_data**, or **energy_cost** endpoint with the **scenario id** as a parameter to retrieve the desired data.

Chapter 6

Summative evaluation

In this section, we present the evaluation of our IT artefact, aimed at addressing the two research questions. The evaluation study focuses on two key dimensions. Firstly, we examine the effectiveness of the system in enhancing users' comprehension of the recommended energy technologies and their advantages. Secondly, we gauge the level of trust that users place in the recommendations provided by the system. Additionally, we seek to explore whether the information presented influences users' perspectives and behaviours, encompassing aspects such as their familiarity with energy-efficient technologies and their inclination to adopt them.

As highlighted in Nunes and Jannach's summary [41], there is no universally accepted definition of what constitutes a correct or best explanation, evaluating the quality of explanations relies on capturing the subjective perceptions of users and monitoring the impact of these explanations on user behaviour, and user studies have been the predominant research method for assessing explanations in recommender systems. Aligned with this understanding, our goal of capturing the subjective perceptions of users regarding the explanations provided and their attitude changes, we have made the decision to conduct real-user studies.

Due to time constraints imposed by the university's requirements for a master's thesis, we conducted qualitative user studies with 7 participants in Germany. While the sample size was small, qualitative studies provide valuable insights into rusers' perceptions, attitudes, and experiences.

Goals

The evaluation aims to achieve two primary objectives, to understand:

- Efficacy in addressing the information gap.
- Level of trust towards the recommendations.

6.1 Semi-structured interviews

The interview proceeds through the following steps.

1. Express gratitude to the interviewee for their willingness to participate and introduce myself briefly.
2. Provide a brief recap of the project, emphasising its purposes, and clarify the specific objectives of the interview.
3. Inform the interviewee about the expected duration of the interview and assure them that the recording will be used solely for transcription purposes, ensuring confidentiality.
4. Explain that the interview will involve participants using the web service to explore and discover recommendations tailored to their home situations.
5. Prior to participants using the service, they will be asked a series of questions pertaining to their demographic information and initial perceptions of energy technologies.
6. Ask participants to use the service using a laptop and encourage them to think-out-loud while navigating.
7. When the participants finished interacting with the service, other questions will be asked.
8. Inquire if the interviewee has any remaining questions or uncertainties.
9. Express appreciation once again for their participation and inform them that they can reach out with any further concerns or inquiries they may have.

Target groups

The target users of this study are individuals residing in Germany who own or live in single-family houses. The participants were recruited using a convenient sampling approach. We employed a snowball technique by reaching out to acquaintances to inquire about their residence in a single-family house or their knowledge of individuals residing in such properties.

The interview invitation is composed as follows:

Are you a homeowner in Germany with a single-family house? Do you want to make informed investment decisions about energy technologies for your home? If so, we invite you to participate in a 1-hour interview for our web service developed in collaboration with the University of Siegen. Don't miss out on the opportunity to finding out some energy technologies to invest for your home that potentially save energy cost. During the interview, you will use our online service and share your experience. Rest assured that all information shared will be kept confidential and anonymised. The interview will be conducted either remotely or in person as you prefer. If you are interested, please choose your preferred time slot by clicking on the following link: https://calendar.app.google/F8RnWSKmnofz3cHf6. If you have any questions, feel free to contact us. Thank you for considering collaborating on the project!

Every participant took part in the evaluation signed a consent form (Appendix D) before starting. A summary of the participants can be found in Table 6.1.

ID	Gender	Age	Nationality	Occupation
PA	M	60	Germany	Constructor
PB	M	30	Germany	Researcher
PC	F	28	Taiwan	Master student
PD	F	69	Germany	Retired professor
PE	M	69	Germany	Retired professor
PF	M	29	Austria	PhD student
PG	M	28	Germany	PhD student

Table 6.1: Participants

Material

- **Laptop:** Participants will be provided with a laptop to access and use the web service before the interview.

- **Recording Device:** A mobile phone for instance, will be used to capture and record the interview session to enable accurate transcription of the interview responses for analysis and reference.
- **Interview Guideline:** A printed copy of the interview guideline.
- **Pen and Papers:** A pen and some papers to jot down any notes or additional information during the session.
- **Translator:** In the event that participants are not comfortable with the English language, a German speaker will be present to assist in facilitating communication and ensuring a clear understanding of the questions and responses.

Welcome

Thank you for participating in this interview. My name is Yanwei Miao, and I am currently working on my master's thesis project in collaboration with Fraunhofer ISI. We developed a web service to help homeowners like you make informed decisions about investing in energy technologies for your homes. Our aim is to provide personalised recommendations based on your specific circumstances, enabling you to determine the economic feasibility of implementing these technologies. To proceed, we kindly request your cooperation in answering a few questions about your background. This will help us gain a better understanding of your knowledge and perspective on AI and energy technologies. Once is complete, we will guide you through the web service to obtain personalised recommendations for your home energy system. While using the service, we encourage you to think out loud and share your thoughts and observations. Afterward, we will conduct an interview to gather your feedback and insights. If you have any questions at any point, please don't hesitate to ask. Are you ready to begin?

Questions

The interview questions can be categorised into four main categories: *demography, knowledge, trust, and additional questions*. Demography questions focus on gathering information about the background of the interviewees, aiming to identify any demographic factors that may influence their interest in more detailed explanations. Explainability questions are designed to assess the clarity and comprehensibility of the provided explanations, aiming to determine if they are clear and understandable to the participants. Attitude change questions are divided into two parts: before using the service and after using the service. These questions aim to capture any changes in participants' attitudes towards energy technologies and their perception of the recommendations after using the service. Lastly, additional questions or thoughts may arise during the interview. They could be an opportunity to explore additional insights or address any specific concerns during the conversation.

Category	**Questions**
Before using the web service	
Demography	Gender Age Educational background Occupation Nationality Knowledge and interest in AI Knowledge and interest in the energy domain
Knowledge	Have you heard of energy-efficient appliances or renewable energy technologies for households? Have you ever considered implementing energy-efficient technologies, such as solar panels and smart thermostats in your house? What is your understanding regarding the benefits of energy-efficient technologies? Do you know climate change and why it is important for individuals to save energy and utilise renewable energy sources?
After using the web service	
Trust	How do you feel about the recommendations provided? Do you find the recommendations useful or valuable? Are you considering investing in any of the recommended technologies now? Why or why not? What factors influence your decision to adopt or reject the recommendations? Do you know why the recommendations were recommended to you? Do you trust the recommendations? Why or why not? What factors contribute to your trust or lack of trust in the recommendations?
Knowledge	Were you familiar with these technologies before using the system? Did the system provide enough information for you to understand the technologies?

	Has your knowledge of energy efficient technologies improved as a result of using the system? Do you believe adopting these technologies can lead to lower energy costs? Why or why not?
Additionals	Give participants an opportunity to share any additional thoughts, concerns, or suggestions regarding the system and its recommendations. Ask if they have any questions for you or if there's anything else they would like to discuss.

Table 6.2: Interview guideline

Closure

Thank you so much for taking the time to participate in this interview session. I sincerely appreciate your willingness to share your thoughts and experiences with us. If you have any further questions, concerns, or additional insights that you would like to share, please don't hesitate to reach out.

6.2 Future work: Kano survey

The Kano model [48] is a commonly used framework in quantitative research to understand customer satisfaction and prioritise features or attributes. In our project, we aim to also incorporate the Kano model survey (Table 6.3) as part of our future work. We plan to integrate this survey directly into the web service, allowing individuals who have interacted with the service online to voluntarily complete the survey. Through the integration of the Kano survey into the web service, we have the opportunity to collect insights from users who engage with the service online. This will enable us to assess whether the inclusion of specific features in the service brings delight to our users. This assessment will help us determine the necessity of explanations in the service as well.

Features	I like it	I expect it	I'm neutrual	I can tolerate it	I dislike it

Show corresponding yearly energy bill					
Don't show corresponding yearly energy bill					
Show detailed simulated yearly energy consumption					
Don't show detailed simulated yearly energy consumption					
Show detailed simulated daily energy consumption					
Don't show detailed simulated daily energy consumption					
Show climate change information					
Don't show climate change information					
Allow exploring and adjusting configurations of the recommended technologies					
Don't allow exploring and adjusting configurations of the recommended technologies					
Show comparison with current situation					
Don't show comparison with current situation					
Show explanation of each technology					
Don't show explanation of each technology					
Show total investment costs of each technology					
Don't show total investment costs of each technology					
Show annualised investment costs of each technology					
Don't show annualised investment costs of each technology					

Table 6.3: Kano survey

6.3 Analysis

A thematic analysis methodology was employed during this process. This involved transcribing all the interviews and capturing participants' insights on digital sticky notes within the Miro board software. Subsequently, these notes were categorised into four topics: *knowledge, trust,* *driver, and others*. Under the "knowledge" category, the aim was to assess participants' comprehension of energy technologies and associated benefits before and after engaging with the service. For a comparison of their understanding and potential learning outcomes. The "trust" theme aimed to understand the level of trust participants had in the recommendations and the overall system. It also explored the factors contributing to their trust. Within the "driver" category, the focus was on identifying key factors influencing participants' decisions to invest in energy technologies. The goal was to explore whether the service adequately addressed these drivers and if it met participants' needs in this regard. The "others" category accommodated insights that did not fall precisely within the predefined themes.

Once all the thoughts were organised into the designated topics, a further step was taken to assign tags to each insight. These tags distilled the main concept of each insight, aiding in the analysis process. For instance, within the "knowledge" category, insights were labeled with tags such as "energy technologies," "energy prices," "energy policies," "climate change," "human comfort," "AI," "fact," and "green behaviour," in accordance with the specific focus of each insight. This tagging approach was applied across all categories. In additon, in the "trust" category, trust-related insights were documented on white sticky notes, while distrust-related insights were noted on black ones. Using these tags, the analysis sought to uncover patterns and draw meaningful conclusions. An illustration of this process is depicted in Figure 6.1, showcasing the sticky notes on the Miro board, which served as a visual representation of the thematic analysis.

Figure 6.2, Figure 6.3, Figure 6.4, and Figure 6.5 display the categorised clusters of sticky notes for each respective topic.

Table 6.4 provides an overview of participants' general understanding and interest in artificial intelligence and energy technologies, along with their perspectives on the service's learnability and explainability.

Moreover, the complete interview transcripts are available in Appendix **??**.

Participant A

Before using the service, Participant A, who works in the house construction industry, displayed knowledge of EU energy policy and familiarity with energy-efficient appliances and renewable

Figure 6.1: Thematic analysis

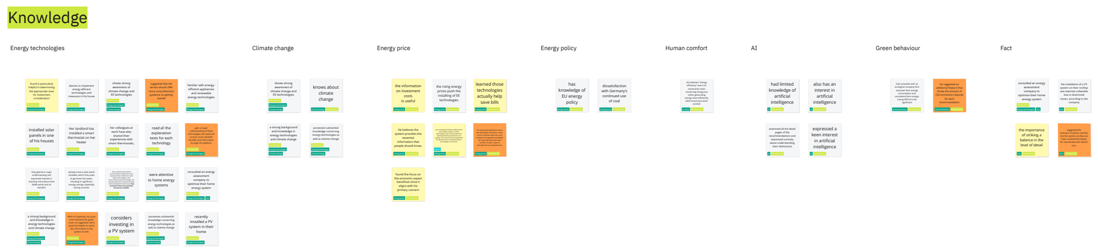

Figure 6.2: Thematic analysis: Knowledge

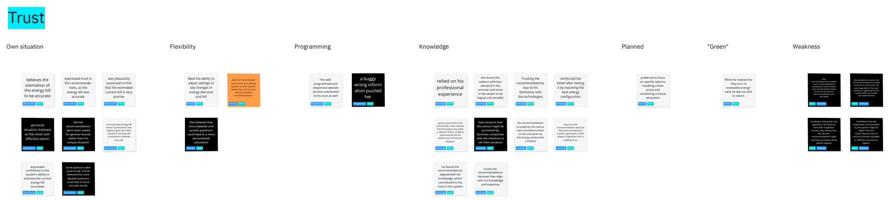

Figure 6.3: Thematic analysis: Trust

energy technologies. He had implemented solar panels in one of his houses and believed in their ability to reduce energy costs for households. Participant A emphasised the rising energy prices and the importance of addressing climate change, expressing dissatisfaction with Germany's continued use of coal.

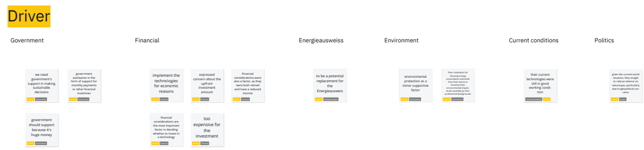

Figure 6.4: Thematic analysis: Driver

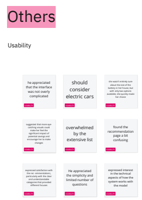

Figure 6.5: Thematic analysis: Other

ID	Interest in AI	Interest in energy	Learned more	Trust
PA	No	Yes	No	Yes
PB	No	Yes	Yes	Yes
PC	No	No	Yes	Not much
PD	No	Yes	Yes	Yes
PE	No	Yes	Yes	Yes
PF	Yes	Yes	No	Yes
PG	Yes	Yes	No	Yes

Table 6.4: Participants' understanding and perspectives

During the service usage, Participant A found the service to work smoothly, receiving a comprehensive list of around 50 recommendations to lower energy costs. While he agreed with most configurations, he felt overwhelmed by the extensive list and preferred to focus on specific options such as installing a heat pump and conducting a house renovation, given his expertise in his own house's needs. Despite not finding recommendations for biomass utilisation, Participant A relied on his professional experience and personal resources in considering biomass as the most cost-effective option. Although he missed the last level of explanation on renewable energy benefits, he clicked to view more details on the specific recommendation he sought.

After using the service, Participant A appreciated the recommendations but felt they were more suited for general houses rather than his unique situation. Financial considerations and environmental impact guided his energy technology decisions. Trusting the recommendations due to his familiarity with them, he acknowledged the service provided an overwhelming amount of information and a surplus of recommendations.

Participant B

Before using the service, Participant B, who works in the renewable energy industry, expressed a strong awareness of climate change and a desire to implement energy-efficient technologies and measures in his house primarily for economic reasons.

During the service usage, Participant B found the service to be simple, clean, and straightforward, which he appreciated. Although the service did not consider his electric car, he believed the estimation of the remaining energy bill to be accurate. He found the information on investment costs to be useful and liked the ability to adjust settings to see changes in energy demand and bill. While he noticed the ”why turn to renewable energy” card, he did not click to view it.

After using the service, Participant B found it particularly helpful in determining the appropriate sizes for investment consideration. He believed that implementing these technologies could lead to energy cost savings, but expressed concern about the upfront investment amount, which posed a barrier for him. He suggested that government assistance in the form of support for monthly payments or other financial incentives could make green living more accessible. Participant B also suggested that the service should offer more comprehensive guidance on getting started and allow for more detailed inputs, such as providing options to enter specific details like roof size and receive insulation recommendations. He expressed trust in the recommendations, as the energy bill was accurate when not considering the electric car. The well-programmed and responsive website service contributed to his trust as well, and he appreciated that the interface was not overly complicated.

Participant C

Before using the service, Participant C, a current master’s student in human-computer interaction, admitted that she doesn’t have much knowledge or interest in artificial intelligence, nor energy technologies. She does have a smart thermostat installed on her heater, which was provided by her landlord, and she is familiar with how it operates. Additionally, her colleagues at work have also shared their experiences with smart thermostats, as many of them have one. She holds the belief that the concept of “energy efficiency” does not necessarily mean conserving energy but rather generating energy more efficiently, while ensuring human comfort.

During the service usage, Participant C carefully read all the explanation texts for each technology while providing the current configuration of her house. She wanted to ensure that she answered correctly. When selecting the battery capacity, she wasn’t entirely sure about the size of the battery in her house, but with only two options available, she quickly made her choice, believing that the battery in her house should be a larger one. After receiving the estimates of her current annual energy bill, Participant C calculated the monthly bill herself and was pleasantly surprised to find that it was very precise. She then proceeded to choose a recommendation and closely examined the accompanying energy graphs. Noticing that the energy demand bars for each month showed variations, with less demand in the summer and more in the winter, she found this pattern to be logical and sensible. However, she also encountered a confusing aspect when she noticed an energy bar for cooling, even though she didn’t have an air conditioner in her house. This information puzzled her. Participant C also clicked on the climate change education card to quickly scan its content and appreciated the information being presented in that section.

After using the service, Participant C found it to be a potential replacement for the Energieausweis, a nation-wide recognised standard in Germany for displaying a house’s energy-efficiency level, which people usually need to pay professionals for. She appreciated that the recommendations were presented in a neutral manner, but suggested that more eye-catching visuals could make her feel the significant impact of potential savings and encourage her to make changes.

Participant C felt that the recommendations might not perfectly align with her own situation, because the questions asked in terms of her energy consumption behaviours, were relatively general. She believed that more detailed and private questions could lead to a more personalised calculation. Regarding trust, she initially believed in the service, especially after seeing that the estimated energy bill was accurate. However, when she encountered confusion in the graph, her trust in the system wavered. Participant C had concerns that the service might be promoted by business companies with the intention to sell their products. This led her to believe that the algorithm behind the model might be biased and pushing users to spend money. However, after it was clarified that the project was solely a research-driven initiative sponsored by the

EU without any commercial influence, she gained more trust in the service. To further validate her trust in the system, she decided to test it by inputting the best energy configuration. The service did not provide any recommendation for this situation, which reinforced her belief that the system was not solely focused on pushing users to spend money. This positive experience increased her trust in the service and the recommendations.

Participant C also mentioned that her investment willingness was influenced by various factors, including how long she planned to stay in her current house and whether she could take the technologies with her when moving. In her background, households were not allowed to privately install PV systems without obtaining a certificate from authorities, and selling excess electricity back to the grid was prohibited. which differs from Europe where governments encourage PV installations. Upon learning about these differences, she became enthusiastic about installing a PV system, recognising its benefits in both cost savings and contributing to environmental preservation.

Despite not having much prior knowledge of energy technologies, Participant C was able to answer all questions about her current house after reading the descriptions provided. She mentioned that the service allowed her to gain a rough understanding of these technologies but expected to learn more detailed benefits and information through the platform.

Participant D & E

Before using the service, Participant D and Participant E, a couple, had limited knowledge of artificial intelligence but were attentive to home energy systems. They already had a solar panel installed, which they used to generate hot water, resulting in significant energy savings, especially during summer. Seven years ago, they consulted an energy assessment company to optimise their home energy system. The company assessed the feasibility of installing various technologies and provided suggestions. Notably, the installation of a PV system on their rooftop was deemed unfeasible due to directional issues, according to the company.

While they wished to transition to more energy-efficient technologies eventually, some of their current technologies were still in good working condition. They planned to replace them in the future when they no longer served efficiently. Their motivation for reducing energy consumption stemmed from their desire to minimise their environmental impact, driven possibly by their professional backgrounds. Moreover, given the current world situation, they sought to reduce reliance on natural gas, particularly due to geopolitical concerns, as they preferred not to buy gas from Russia. Financial considerations were also a factor, as they were both retired and have a reduced income.

During the service usage, Participant D and Participant E found the recommendation page a bit confusing, but they understood it better after I explained the page. The estimated energy bill shown by the service was slightly higher than their actual bill, but they still considered it relatively accurate. They carefully examined the recommended configurations and expressed their intention to install certain technologies in the future, despite some technologies, the energy assessment company deeming them unfeasible for their house. They wondered if there were portable alternatives available. Additionally, they were unfamiliar with the SEMS system, but after reading the provided explanation, they gained a rough understanding and expressed interest in learning more about how it works and its benefits. They found the energy visualisation feature interesting and, with my guidance, explored the additional information on climate change and energy-saving measures for individuals. They briefly read through the information and agreed with the suggested measures, mentioning that they already follow some of those practices. They also shared that they had consulted with an ecological company that assessed their energy consumption and considered their energy-saving efforts to be significant. In an effort to be more energy-efficient, they even turned down the temperature a bit, and dress more in the house.

After using the service, Participant D and Participant E noted that the recommendations provided by the service were somewhat similar to the ones given by the energy assessment company. However, they highlighted that the energy assessment company provided more personalised suggestions as they physically visited their house and could offer more precise advice tailored to their specific situation. Despite this, they expressed trust in the service's recommendations, particularly because they were provided by a trusted organisation, which played a significant role in building trust. However, they trust the assessment company more, as they believed the professionals could consider more intricate details of their house and calculate the economic feasibility more accurately. Since Participant D and Participant E live in a house with shared walls with neighbors, they emphasised that several additional factors should be considered when installing new technologies. For example, changes to insulation on the rooftop or walls and the feasibility of installing a heat pump may depend on the distance from their neighbors' houses. Consequently, they believe that the service's recommendations might not fully encompass these specific aspects. Furthermore, they expressed a concern that the recommendations provided by the service may remain the same regardless of the input conditions, suggesting that the system might not consider personalised details. This led to a slight skepticism regarding the variability and suitability of the recommendations under different circumstances.

Participant F

Before using the service, Participant F is pursuing a PhD degree in the energy domain, indicating a strong background and knowledge in energy technologies and climate change. Additionally, Participant F also has an interest in artificial intelligence.

During the service usage, Participant F found the experience to be smooth and had no difficulties receiving the recommendations. He expressed confidence in the system's ability to estimate the current energy bill accurately. Despite all the recommendations suggesting investments that would not yield cost benefits (i.e., the annualised investments exceed potential savings on energy bills), Participant F still considers investing in a PV system. He believes that the investment costs provided by the system might be higher than the actual situation due to various subsidies available in different countries or regions, which could potentially reduce the overall investment. While Participant F appreciated the bar charts displaying electricity demand and generation, he suggested an additional feature that shows the amount of CO_2 emissions reduced for each recommendation. He believes that such a feature would allow for a more contrasting comparison, as the electricity consumption alone may not clearly indicate the environmental impact. He mentioned that when some recommendations show higher estimates than the previous ones, having this CO_2 reduction information could provide a more obvious indication of their positive impact.

After using the service, Participant F expressed satisfaction with the recommendations, particularly with the clear and understandable categories that provided different focuses. He trusted the recommendations and the estimations of energy consumption. Besides the investment costs provided by the system might be higher than the actual costs due to potential subsidies not considered in different areas, especially when it comes to investing in a PV system. For Participant F, financial considerations are the most important factor in deciding whether to invest in a technology. As someone working in the related field, he found the recommendations aligned with his knowledge, which contributed to his trust in the system. With his expertise, he could even interpret the graph to determine how much hot water was heated by the PV system and how much was produced by the boiler. He suggested that it would be helpful to clarify this information in the system as well.

Participant G

Before using the service, Participant G is a researcher specialising in energy systems, and thus, he possesses substantial knowledge concerning energy technologies as well as cliamte change. He also expressed a keen interest in artificial intelligence. Participant G lives with his family and recently installed a PV system in their home.

During the service usage, Participant G navigated through all the questions effortlessly and successfully received all three recommendations. He appreciated the simplicity and limited number of questions, although he is able to provide more detailed answers. However, he considered that regular homeowners might not be able to answer more intricate questions. Participant G carefully examined all the detail pages of the recommendations and expressed curiosity about understanding their distinctions.

After using the service, Participant G found the focus on the economic aspect beneficial since it aligns with his primary concern. He and his family are considering installing a SEMS system and a battery system, as these technologies were recommended and demonstrated the potential for cost savings. This assurance has strengthened his determination to implement these technologies in his house. He believes the system provides the essential information that people should know.

One concern raised by Participant G was related to house renovation costs, as he considered them too expensive for the investment. He expressed skepticism about the estimated renovation costs, as he is familiar with how such numbers are typically calculated. He inquired about the total number of years used to calculate the annualised costs. Participant G suggested the inclusion of electric vehicles into the system, as they can have a substantial impact for households with electric cars.

Being well-versed in the energy sector, he has a great understanding of how electricity is managed. In fact, he could even explain the energy demand and generation graphs based on his expertise. Overall, Participant G trusts the recommendations because they align with his knowledge and expertise. However, he pointed out that some questions were quite broad, and he believed that more detailed questions could lead to more accurate results. Nonetheless, he acknowledged the importance of striking a balance in the level of detail.

In the end, Participant G expressed interest in the technical aspects of how the system works with the model.

6.4 Discussion

As per the participants' feedback, all of them show a strong awareness of climate change. Four of the participants, who work in energy-related fields, have significant knowledge about energy technologies due to their job experiences. Two participants gained their knowledge from consulting experts in the field. Only one participant had limited familiarity with energy technologies. Furthermore, all participants, except this one, have either already installed or are planning to install energy-efficient technologies in their homes. This is likely because individuals who are already interested in energy topics are more inclined to take part in this kind of research.

Participants lack of knowledge wish to learn more

In terms of energy technologies, participants who already had some knowledge didn't significantly enhance their understanding through the service. Only two participants, who were unfamiliar with SEMS, learned about this specific technology. Together with the one participant with limited prior knowledge appreciated the general overview provided by the service but found it lacking in depth. They expressed a desire for more detailed information on the technologies. It seems that offering only basic explanations isn't sufficient. There's a need to provide additional detailed information for users keen on expanding their knowledge about these technologies.

Financial considerations drive decisions

All participants emphasised the critical role of the financial aspect when making decisions about energy technology investments. As stated by one participants,

> "The focus on the economic aspect is beneficial since it is my primary concern.".

This sentiment was reinforced by a participant from the construction field, who highlighted the impact of rising fuel and gas prices as a driving force behind people's shift towards renewable energy due to its cost-effectiveness.

One participant mentioned the information on investment costs is crucial, helping him make informed decisions. Moreover, the estimated energy bills were deemed valuable for determining the technology choices and sizes, as another participant explained. Furthermore, one participant's preferred technologies were recommended by the service, leading to increased confidence in the investment due to the estimated bill reductions.

The participant with limited knowledge of energy technologies recognised the potential for significant cost savings through the service, this feedback shows the significance of maintaining an emphasis on financial aspects within the service, showcasing its potential to bridge the information gap in this vital area. The focus on financial considerations not only aligns with participants' primary concerns but also serves as a key driver in encouraging sustainable energy choices.

Energy professionals seeking in-depth information

In our evaluation, all three participants with expertise in the energy sector shared a common request for more comprehensive information regarding the recommendations provided. They demonstrated a strong ability to interpret the visualised charts depicting energy demand and generation. Moreover, they are interested into the technical intricacies of the model or algorithms.

One participant expressed interest in having the reduction amount of CO_2 emissions displayed for each recommendation. This participant believed that this information would present more obvious differences than the energy charts, and also providing a clearer understanding of the environmental impact of different choices. Another participant indicated a desire to understand how the renovation costs were calculated. The feedback from participants with professional energy knowledge underscores their inclination towards acquiring more comprehensive details of the model, revealing their pursuit of in-depth explanations and a desire to make informed decisions based on these insights. They request greater transparency in the system's underlying processes.

Solid trust across participants

In our evaluation, all participants expressed trust in the recommendations provided by the system. This trust was fortified by several factors, each playing a role in building their confidence.

Accurate energy bill estimations build credibility

Mentioned by all participants, a significant contributor to this trust is the perceived accuracy of the estimated current energy bills. Participants' conviction in the correctness of these estimates was instrumental in fostering trust in the recommendations.

Professional expertise bolsters trust

Participants engaged in energy-related fields resonated with the recommendations due to their alignment with their professional knowledge. This correspondence between the system's suggestions and their expertise augmented their trust in the system's advice.

Trusted source and research institution

For some participants (3 out of 7), the fact that the service was developed by a trusted organisation was a significant trust-building factor. This is evidenced by one example, one participant initially had doubts, fearing that the service might be influenced by business interests promoting specific energy technologies. However, these concerns diminished as the participant noticed that certain configurations received no recommendations, revealing the service's impartiality. His trust solidified upon learning that the service was crafted by a research institute rather than a commercial entity. Therefore, the importance of transparently conveying the intention to users is evident.

Consistency with past recommendations reinforces confidence

Two participants who had prior experience with energy audits found the recommendations from the service to be consistent with those obtained elsewhere. This alignment reinforced their confidence in the service's recommendations.

Design and user experience boosters confidence

Another participant highlighted the role of the well-designed, responsive web interface in building trust. A user-friendly interface contributes to a sense of professionalism and reliability, further strengthening trust in the system.

Personalisation concerns

The feedback received also highlighted concerns regarding the level of personalisation in the recommendations. Notably, participants underlined situations where their unique circumstances weren't fully accounted for.

Unique resources situations

Among the participants, some (2/7) presented unique circumstances. A participant, who works in the house construction field, believed that his house's situation differed from typical households. This participant emphasised that a biomass boiler was a more economical solution for him. His house had ample space for wood storage due to a large garden, and his proximity to forests meant that biomass prices were lower for him. A similar sentiment was echoed by another participant who couldn't install a PV system due to specific directional constraints of their house. This information was informed by professionals during an energy audit.

Unique consumption behaviours

Another participant mentioned that the service didn't delve into his specific energy consumption behaviours. He believed his energy usage differed from the norm, which might impact the accuracy of the estimations. Similarly, another participant expressed concerns, suggesting that certain questions in the service could be more detailed. This participant believed that greater detail in the questions could lead to more accurate calculations and recommendations. These observations underscore the need to strike a balance between simplicity and detail in the questions presented to users.

Regional variations in investment costs

From a financial perspective, one participant brought up the point that investment costs could fluctuate based on regional differences. This is due to varying subsidy policies that are often tied to specific geographical areas.

Beyond technologies

In addition to the focus on energy technologies and their sizes, few participants (2/7) expressed a desire for more granular and comprehensive recommendations. One participant expressed an interest in receiving recommendations for the materials to be employed in rooftop renovations. Another participant expressed a need for greater clarification on how to initiate changes in their energy system. These insights emphasise the significance of considering users' holistic needs and expanding the scope of recommendations to encompass various aspects of energy-efficient enhancements to ensure a more comprehensive and user-centric approach, catering to a diverse range of user preferences and requirements.

Motivations for investment: financial and beyond

The driving force behind participants' motivation to invest in energy-efficient technologies predominantly revolves around financial considerations. The allure of potential cost savings on energy bills appears to be the primary incentive for most participants. Additionally, environmental protection emerges as a notable supporting factor in participants' decision-making. While financial benefits are at the forefront, the desire to contribute positively to the environment underscores a collective recognition of the importance of sustainable energy practices. It's noteworthy that nowadays geopolitical concerns also play a role for a subset of participants.

Government support

In terms of financial implications, the participants shared a consensus that investing in a sustainable energy system involves substantial financial commitment. This sentiment echoes the general understanding that adopting energy-efficient technologies often requires a significant upfront investment. A substantial portion of the participants (3/7) expressed the view that government support should play a pivotal role in facilitating the adoption of sustainable energy systems. This insight emphasises the role of governments in incentivising and promoting the adoption of energy-efficient technologies, potentially through subsidies, tax benefits, or other forms of financial assistance.

A multifunctional perspective

An intriguing perspective arose from one participant, shedding light on the multifunctional potential of the service. Beyond its primary role of offering energy system recommendations, this participant recognised the service as a potential alternative to the commonly required "Energieausweis" (energy certificate) [57] in certain regions. This certificate is a significant document used to assess a property's energy efficiency, typically mandated for property transactions and rentals. Such multifunctionality adds a layer of versatility to the service, potentially expanding its reach and relevance within the energy domain.

Chapter 7

Conclusion

Our exploration to bridge the gap in knowledge about energy technologies and the associated benefits for homeowners has yielded valuable insights.

The journey began with an initial phase of pre-study, where our goal was to uncover existing tools and practices that could empower homeowners to embrace sustainable energy solutions. This initial investigation paved the way for the development of an innovative home energy system recommender, anchored in the FLEX models. These models assist in identifying technology configurations tailored to specific home situations, leading to potential energy cost savings that directly benefit homeowners financially. Through this process, homeowners became acquainted with technologies and their associated benefits.

Throughout the design process, we placed significant emphasis on explainability, ensuring the recommendations were trusted. By engaging with real participants through user testing, we have gained a deeper understanding of their expectations, concerns, and attitudes. The insights gathered from the feedback lead us to a conclusive observation.

Learning and information gaps

The provision of information significantly influences homeowners' decision-making, despite slight variations in user responses. These differences underscore varying perspectives and positive attitudes towards investing in such technologies. Users with limited knowledge about energy technologies before using the service expressed gaining a better understanding of various technologies, their functionalities, and the potential financial benefits. In addition, participants who were already knowledgeable in this field learned about the impact of different configurations and sizes of technologies tailored to their unique situations. While participants with related professional knowledge did not notably enhance their understanding through the service regarding the technologies, those unfamiliar with specific technologies appreciated the general overview but desired more detailed information. Thus, the need for additional depth in explanations became apparent.

Furthermore, drawing from participants' feedback, it is evident that the service effectively emphasised the financial perspective, a key element that piqued the interest of homeowners. Further insights into homeowners' viewpoints on financial aspects will be explained more below.

Trust and confidence in the system

Moreover, trust within a recommender system, plays a critical role in nurturing user confidence and promoting well-informed decisions. As discussed in the previous chapter, user feedback has unveiled various factors influencing trust and distrust in both recommendations and the system. Our recommender system incorporates three levels of explanations, each soliciting responses from users. The first level of explanation, which centers on annual energy bills and provides a comparison with their estimated current bills, garners appreciation from all users. This aspect contributes to building trust in the system, aligning with their financial concerns and enabling a comparison between estimated and real-world situations. The second level of explanation, visualising energy consumption patterns, is also well-received by users. This visualisation resonates with their understanding of consumption habits and further bolsters their trust. Additionally, the ability to freely modify configurations and compare results plays a vital role in enhancing trust. Witnessing the differences between configurations fosters the belief that the system tailors recommendations to individual situations, rather than offering one-size-fits-all suggestions.

However, the third level of explanation – the educational information, appears to be less appealing to many users, potentially due to its less user-friendly interaction design involving extensive text. Furthermore, as many users are already familiar with the concept of climate change, this section often serves as a self-checklist rather than a trust-building element. Consequently, this level of explanation may not significantly contribute to user trust in the recommendations or the system. Nevertheless, it serves as valuable supplementary information, allowing users to reflect on their current behaviours and potentially consider more sustainable choices.

Overall, only one participant, who initially lacked interest in energy, displayed some skepticism. In general, participants expressed confidence in the recommendations, attributing their trust to factors like precise energy bill estimations, alignment with professional expertise, and the credibility of the service's source. The well-designed interface further contributed to a sense of professionalism and reliability, fostering confidence in the system.

In addition to the aforementioned perspectives that the study aimed to emphasise, the study also found insights regarding the following aspects.

Participant awareness and background

The participants demonstrated a collective and robust awareness of climate change. Notably, most participants were either current adopters or considering the installation of energy-efficient technologies in their homes, reflecting a pre-existing interest in energy topics.

Financial considerations and motivations

Furthermore, in alignment with findings from previous studies and surveys, our research highlights the enduring significance of financial considerations as a primary motivating factor. Nonetheless, a notable shift is observed in our study, where participants express an increasing desire to contribute to environmental protection. It is noteworthy that this "green" inclination, while supportive, remains secondary to the financial aspect due to the substantial investment required. However, this change in attitude is distinct from the situation observed in a survey conducted in 2013 [44]. This evolving perspective suggests a growing awareness and willingness among individuals to embrace more sustainable energy decisions.

Financial aspects remain as pivotal in participants' decision-making processes, with potential cost savings being a primary motivator. The transparency of investment costs and estimated energy bills played a crucial role.

Personalisation and user concerns

User feedback highlighted concerns related to the level of personalisation in recommendations. Unique circumstances, consumption behaviours, and regional variations in investment costs underscored the necessity for a balanced approach, balancing a simplified design questionnaire with detailed consideration of user situations.

More specific recommendations and user needs

Beyond energy technologies, participants expressed interest in recommendations for materials and renovations. This suggests a need for a more comprehensive approach to accommodate diverse user preferences and requirements, considering various aspects of energy-efficient enhancements.

Government support and policy implications

Participants emphasised the significant financial commitment involved in adopting sustainable energy systems and called for substantial government support.

Multifunctionality and service impact

Participants recognised the multifunctional potential of the service, viewing it as a possible alternative to the ”Energieausweis” in Germany. This multifaceted utility could add versatility to the service, potentially expanding its reach and relevance in the energy domain.

In accordance with Fogg's Persuasive Design framework [23], where he outlined how technology can effectively influence and change behaviours by considering three key factors: *motivation, prompt, and ability*. Our study reveals that a considerable number of households exhibit strong “motivations” to embrace energy-efficient technologies. The introduced home energy system recommender functions effectively as a “prompt,” providing valuable insights and recommendations that facilitate their decision-making processes. Although, there is room for improvement in this artefact, as discussed in the previous chapter, for instance, users with varying levels of knowledge about energy technologies express their specific informational needs. We envision a promising future for tools like ours. These tools not only provide valuable information to households, fostering financial benefits and sustainable energy investments, while also potentially aiding in mitigating climate change. However, a prevalent “ability” constraint emerges among many households, primarily associated with financial challenges that impede one-time investments in these technologies. This emphasises the necessity for policy interventions aimed at improving accessibility and affordability. We believe that through the provision of accessible information and collaborative efforts from governing bodies, this trend of embracing sustainable energy choices will continue to grow, encouraging more individuals to take meaningful steps toward a greener and more energy-efficient future.

7.1 Next steps

Based on the preceding analysis, several key directions emerge for future development:

There is a need to provide access to more comprehensive and detailed information regarding the recommended technologies. This could involve incorporating additional explanations, or links to external resources to facilitate a deeper understanding of the technologies.

Considering the positive response to the comparison of energy consumption patterns, adding further information like CO_2 emission comparison graph could enhance the users' decision-making process, providing them with another perspective on the environmental impacts of their choices.

Personalisation remains a cornerstone for building trust and user engagement. Thus, allowing users to input more personalised data related to their specific context and energy consumption patterns could further enhance the accuracy and relevance of recommendations as well as their confidence in the system.

Additionally, incorporating more detailed insights into the calculation of estimated bills, which may encompass factors such as regional subsidies, would provide users with a more comprehensive understanding of the financial implications associated with their choices.

To broaden the service's utility, the potential integration with the existing “Energieausweis” requirement is worth exploring. Providing an energy certificate as part of the service could serve a purpose of facilitating user understanding and fulfilling a regulatory need.

Expanding the applicability of the service to a broader range of house types should also be considered. This can make the service more relevant and accessible to a wider audience.

The third level of explanation could be more interactive and engaging for users. Incorporating visual aids, interactive elements, and concise text to enhance the overall user experience and understanding.

Additionally, to ensure continuous improvement, integrating the Kano survey into the service would be important to allow for ongoing feedback collection.

Moreover, from a technical perspective, enhancing the flexibility of the service is crucial. Current hardcoded elements should be replaced with more dynamic components to ensure adaptability to evolving technologies and changing user requirements.

By focusing on these next steps, the service can be further refined to provide an even more informative, user-friendly, and effective tool for homeowners making sustainable energy decisions.

7.2 Limitations

This study encompasses certain limitations that need to be considered when interpreting the findings.

Small sample size: The study was conducted with a limited number of participants, which might affect the generalisability of the results.

Limited knowledge background: Approximately half of the participants had a background in the energy domain, which could introduce bias into their perceptions and responses.

Restricted age range: The age distribution of participants was concentrated around two main age groups: approximately 30 and 60 years old. This might limit the representation of perspectives across a wider age spectrum.

Lab studies Due to time restrictions, evaluations were conducted in labs, constituting short-term studies. This might introduce bias and limit the ability to draw conclusions about the long-term performance of the artefact, necessitating more extended and quantitative studies.

Age-related technology challenges: Participants aged 65 and above encountered challenges when engaging with the online tool. Older participants preferred face-to-face consultations and demonstrated higher trust in human experts than in an AI system, potentially affecting overall user experience and the willingness to adopt recommendations, especially among older demographics.

Restricted technology choices Some technologies, like house wind energy generators, are not integrated into the system. The study acknowledges the need to consider integrating more technologies and updating them in a timely manner.

Neglect of rebound effect: The study does not account for the rebound effect [28], which refers to potential changes in household behaviour that could result from adopting energy-efficient technologies and renewable energy. This omission could lead to an oversight in estimating the actual impact on energy consumption and subsequent energy bills. While the model assumes a certain comfort lifestyle as a baseline, any significant behavioural shifts induced by the recommended changes might not be accurately captured. Nevertheless, given the reference to comfort lifestyle, it is assumed that the rebound effect's influence would likely be minimal.

These limitations underscore areas for further investigation and potential refinement of the home energy system recommender to accommodate a broader range of users and contexts.

Appendices

Appendix A

Input of the FLEX models

Category	Data
Behaviour profile	id_hour, people_at_home_profile_1, hot_water_demand_profile_1, appliance_electricity_demand_profile_1, vehicle_at_home_profile_1, vehicle_distance_profile_1.
Battery	ID_Battery, capacity, capacity_unit, charge_efficiency, charge_power_max, charge_power_max_unit, discharge_efficiency, discharge_power_max, discharge_power_max_unit.
Behaviour	ID_Behavior, id_people_at_home_profile, target_temperature_at_home_max, target_temperature_at_home_min, target_temperature_not_at_home_max, target_temperature_not_at_home_min, shading_solar_reduction_rate, shading_threshold_temperature, temperature_unit, id_hot_water_demand_profile, hot_water_demand_annual, hot_water_demand_unit, id_appliance_electricity_demand_profile, appliance_electricity_demand_annual, appliance_electricity_demand_unit, id_vehicle_at_home_profile, id_vehicle_distance_profile.
Boiler	ID_Boiler, type, power_max, power_max_unit, carnot_efficiency_factor.
Building	ID_Building, type, construction_period_start, construction_period_end, person_num, Af, Hop, Htr_w, Hve, CM_factor, Am_factor, internal_gains, effective_window_area_west_east, effective_window_area_south, effective_window_area_north, grid_power_max, supply_temperature.
Energy price	ID_EnergyPrice, id_electricity, id_electricity_feed_in, id_gases, price_unit.
Heating element	ID_HeatingElement, power, power_unit, efficiency.
Hot water tank	ID_HotWaterTank, size, size_unit, surface_area, surface_area_unit, loss, loss_unit, temperature_start, temperature_max, temperature_min, temperature_surrounding, temperature_unit.
PV	ID_PV, size, size_unit.
Region	ID_Region, code, year, norm_outside_temperature.
Space cooling technology	ID_SpaceCoolingTechnology, efficiency, power, power_unit.

Continued on next page

Table A.1 – continued from previous page

Category	Data
Space heating tank	ID_SpaceHeatingTank, size, size_unit, surface_area, surface_area_unit, loss, loss_unit, temperature_start, temperature_max, temperature_min, temperature_surrounding, temperature_unit.
Vehicle	ID_Vehicle, type, capacity, capacity_unit, consumption_rate, consumption_rate_unit, charge_efficiency, charge_power_max, charge_power_max_unit, discharge_efficiency, discharge_power_max, discharge_power_max_unit, charge_bidirectional.
Energy price	Region, year, id_hour, electricity_1, electricity_2, electricity_feed_in_1, gases_1.
Region weather	region, year, id_hour, pv_generation, pv_generation_unit, temperature, temperature_unit, radiation_south, radiation_east, radiation_west, radiation_north, radiation_unit.

Table A.1: Input data of the FLEX-Operation model

Appendix B

Privacy Policy

This Privacy Policy outlines how University of Siegen and The Fraunhofer Institute for Systems and Innovation Research (ISI) collect, use, and protect data for research purposes.

Data Collection

When you use our service, we collect data for research purposes. All data will be anonymous, meaning that we will not collect any personal information that can identify you. The data we collect may include, but is not limited to, information about your usage of the service, your location, and demographic information.

Data Use

We will use the data collected to conduct research and may publish papers based on the findings. The data will be used only for research purposes and will be safely taken care of by and only by all the parties involved in this research, which are University of Siegen and The Fraunhofer Institute for Systems and Innovation Research (ISI).

Data Retention

Please note that once you have used our service, you cannot delete your data. This is because your data will become part of a larger pool of data that will be analysed anonymously. The data will be retained for as long as is necessary for research purposes.

Data Security

We take appropriate measures to protect the data we collect from unauthorized access, use, or disclosure. We use industry-standard security protocols and techniques to safeguard the data from unauthorized access, use, or disclosure. All the parties involved in this research, which are University of Siegen and The Fraunhofer Institute for Systems and Innovation Research (ISI), will have access to the data.

Data Sharing

We do not share the data we collect with third parties, except as required by law or with your explicit consent.

Changes to this Policy

We reserve the right to modify this Privacy Policy at any time, so please review it frequently. If we make any changes to this Privacy Policy, we will post the revised version on our website.

Contact Us

If you have any questions or concerns about this Privacy Policy or our data collection and processing practices, please contact us.

Appendix C

Formative testing survey responses

Q1. What do you think this website is about?	
P1	suggesting some better ways to save energy at home and decrease the cost of that
P2	Energy saving
P3	Calculating how much energy is used per/sqr
P4	I think it is about helping individuals to understand strategies to save money while supporting climate change. It seems to be a hybrid between educate visitors and sell "green energy" services/products.
P5	getting energy-related information in my household

Table C.1: Question 1

Q2. How clear were the instructions on the website for you to follow?				
P1	P2	P3	P4	P5
10/10	8/10	8/10	7/10	5/10

Table C.2: Question 2

Q3. Did you find the website visually appealing?				
P1	P2	P3	P4	P5
10/10	10/10	6/10	8/10	4/10

Table C.3: Question 3

Q4. Was the website easy to use and understand?				
P1	P2	P3	P4	P5
10/10	8/10	7/10	5/10	4/10

Table C.4: Question 4

Q5. How long do you think it took you to complete the questions?				
P1	P2	P3	P4	P5
1-5 min	1-5 min	1-5 min	5-10 min	1-5 min

Table C.5: Question 5

Q6. What would you change about the website to make it more user-friendly?	
P1	adding a ”back” button, in case of returning to the previous page to edit something
P2	1. I didn’t realize if one step moved to the next in the tracker (top left), make you could use a color gradient (i.e. the circles go from light to dark green gradually) to highlight the progress. 2. Is a little weird that the Children’s age is 0-25 (is that the standard in Germany?). 3. It would be great if, in the drop-down menus, there is an ”I don´t know” option. And then provide some guidance for the users to find that out (I saw you already have some questions to support the user, I think that’s very helpful!).
P3	More explanation, cues
P4	”I felt the need for a back button on the interface. For instance, when I clicked on ”more details” on the last page, I couldn’t go back to check the other options. I ended up clicking on the logo that lead to the start of the questionnaire. I also had to Google the PV meaning. It would be more clear if it was written photovoltaic system. I saw there was a link to explain what PV is, but I think it would be more clear for me if it was written photovoltaic because I know what that means. The steps tracker was not that useful as well. It was not reflecting the number of questions. So I was not sure how many questions would be asked until moved to the next step. I am also concerned about the question of the max and min home temperature for me. I never know that as I don’t measure it in my home. I would prefer the questionnaire to provide me with a suggestion based on the ”ideal” temperature. I don’t know if I would decide on an option only by the website usage. Maybe I would like to see more info about the final investment and how much time it would be required to ”get that money back” by saving energy consumption from the power provider. In the PV system, I would like to be able to see how many I would be able to add to my home to understand how much energy it could generate. At first glance, 3.321 kwh seems to be not much. The graphic comparing the current and possible options is not clear. What does it represent? Are the green bars showing how much the PV would generate? Maybe rather than showing many elements (Heating, cooling etc) It would be easier to understand if it don’t show that information too granular.”

P5	”This is difficult to explain in writting. I would rather speak about this. However, here are few things that can be communicated in a written form. The start pages looks nice! but it can be further improved to make it more appealing and gives better vibes. If this was an interview, I would have showed some examples of what I think would improve it. The questions seemed more like a normal survey. I would rather design it so that it looks more like a friendly inquiry rather than a very serious questionnaire. I would include a more friendly language or even use some slang. Also I would include few emojies or even illustations where appropriate. The ’please wait’ page after the questions, gives the impression that the page is not responsive anymore. A more dynamic/moving illustration is expected to know that something is happening and avoid the feeling that the page is lagging. Am I supposed to know information about the battery and PV systems in my house? I was asked for these informations and I am not sure where can I get this information from, if I don’t know it. ’What is a PV system’ and ’What is a battery system’ is not active. So I couldn’t understand what is that.”

Table C.6: Question 6

Q7. Were the recommendations easy to understand?				
P1	P2	P3	P4	P5
10/10	9/10	7/10	5/10	9/10

Table C.7: Question 7

Q8. Was there anything about the recommendations that you found confusing or unclear?	
P1	about PV or SEM systems which I could not see what they are
P2	I love your data visualisation! I would make sure all axis have their respective unit of measure. Just to be extra clear
P3	No
P4	Yes, the bar chart. I think it is also important to understand more clearly the cost of each suggestion and the time to implement such a system.
P5	”In the ’recommendation configuration’ page, the word ’current’ at the top left is not very clear. I stopped for a second and looked at the information below to know what ’current’ referes to here. Also, for a first glance, I was expecting a ’results’ page, before the recommendation appears. Here, all is presented in one page. For the second page, the axes in the ’energy use’ bar chart needs to be named. Also, the annual energy bill is the same for all options. I think it’s a typo here.. Other than that, I think the follow in which the information is presened could be improved.”

Table C.8: Question 8

Appendix D

Consent form

Universität Siegen Fraunhofer ISI

Consent form

Thank you very much for collaborating with us on this project!

Purpose of the Study

The study aims to develop a web service that provides personalised recommendations to homeowners, assisting them in making informed decisions regarding energy investments.

Procedures

If you choose to participate, you will be asked to engage with our web service and answer questions regarding your experience and opinions. The interview is estimated to take approximately 40 minutes, and can be conducted both in person and remotely.

Confidentiality

Your privacy and the confidentiality of your information are of utmost importance to us. Any information collected during the study will be anonymised, and your identity will remain confidential.

Contact Information

If you have any questions, concerns, or require further information, please feel free to contact Yanwei Miao (yanwei.miao@student.uni-siegen.de).

Consent

By proceeding with the study, you acknowledge that you have read and understood the information provided in this consent form. Your participation is entirely voluntary, and you may withdraw at any time without consequences.

Participant Name: Alfred Schkab

Participant Signature:

Date: **03.07.2023**

Thank you again for considering participating in our study.
Your contribution is greatly appreciated!

Universität Siegen Fraunhofer ISI

Consent form

Thank you very much for collaborating with us on this project!

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Contact Information

If you have any questions, concerns, or require further information, please feel free to contact Yanwei Miao (yanwei.miao@student.uni-siegen.de).

Consent

By proceeding with the study, you acknowledge that you have read and understood the information provided in this consent form. Your participation is entirely voluntary, and you may withdraw at any time without consequences.

Participant Name: Aljoscha Pollmann

Participant Signature: A.Pollmann

Date: 07.07.2023

Thank you again for considering participating in our study.
Your contribution is greatly appreciated!

Consent form

Thank you very much for collaborating with us on this project!

Purpose of the Study

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Contact Information

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Consent

By proceeding with the study, you acknowledge that you have read and understood the information provided in this consent form. Your participation is entirely voluntary, and you may withdraw at any time without consequences.

Participant Name: Gounin Chen

Participant Signature:

Date: 19/07/2023

Thank you again for considering participating in our study.
Your contribution is greatly appreciated!

Universität Siegen Fraunhofer ISI

Consent form

Thank you very much for collaborating with us on this project!

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Consent

By proceeding with the study, you acknowledge that you have read and understood the information provided in this consent form. Your participation is entirely voluntary, and you may withdraw at any time without consequences.

Participant Name: Gudrun Willner, Arne Willner

Participant Signature: Gudrun Willner, [illegible]

Date: 25.07.2023

Thank you again for considering participating in our study.
Your contribution is greatly appreciated!

Consent form

Thank you very much for collaborating with us on this project!

Purpose of the Study

The study aims to develop a web service that provides personalised recommendations to homeowners, assisting them in making informed decisions regarding energy investments.

Procedures

If you choose to participate, you will be asked to engage with our web service and answer questions regarding your experience and opinions. The interview is estimated to take approximately 40 minutes, and can be conducted both in person and remotely.

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Contact Information

If you have any questions, concerns, or require further information, please feel free to contact Yanwei Miao (yanwei.miao@student.uni-siegen.de).

Consent

By proceeding with the study, you acknowledge that you have read and understood the information provided in this consent form. Your participation is entirely voluntary, and you may withdraw at any time without consequences.

Participant Name: Philipp Mascherbauer

Participant Signature: P. Mascherbauer

Date: 29.07.2023

Thank you again for considering participating in our study.
Your contribution is greatly appreciated!

Consent form

Thank you very much for collaborating with us on this project!

Purpose of the Study

The study aims to develop a web service that provides personalised recommendations to homeowners, assisting them in making informed decisions regarding energy investments.

Procedures

If you choose to participate, you will be asked to engage with our web service and answer questions regarding your experience and opinions. The interview is estimated to take approximately 40 minutes, and can be conducted both in person and remotely.

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Contact Information

If you have any questions, concerns, or require further information, please feel free to contact Yanwei Miao (yanwei.miao@student.uni-siegen.de).

Consent

By proceeding with the study, you acknowledge that you have read and understood the information provided in this consent form. Your participation is entirely voluntary, and you may withdraw at any time without consequences.

Participant Name: Thomas Haupt

Participant Signature: TH

Date: 4.8.23

Thank you again for considering participating in our study.
Your contribution is greatly appreciated!

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