Filling the Information Gap of House Owners and Technologies: A Design Case Study of a recommender for home energy system

In partial fulfilment of the requirement for the degree of

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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 the 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 house owners. Design Case Studies will be used as the research framework. …

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Notations and Abbreviations

CO_2 Carbon dioxide. 1

EU European Union. 2, 3, 58

GHG Greenhouse gas. 1

HP Heat pump. 27, 28

IV Information Visualisation. 26

NL Natural language. 26

PV Photovoltaic. 10, 12, 14, 16, 18, 27, 28, 51

RS Recommender systems. 21, 23

SEMS Smart energy management system. 18, 27, 28

Chapter 1

Introduction

1.1 Background

Human-induced climate change is causing dangerous and widespread disruption in nature, thereby affecting billions of lives globally [24]. 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 stabilize the concentration of these gases in the atmosphere to limit global warming and its adverse effects [33]. 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 [11]. 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 [33], 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 [11].

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

1.1.1 Mitigating climate change through energy transition

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 [39]. 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 [28], aiming to lead in global climate action and achieve net-zero emissions by 2050 through a socially-fair and cost-efficient transition [10].

1.1.2 Households in energy transition

Households are 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 [12]. 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 [22]. 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.

1.1.3 Technologies for home energy system

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 Opportunity

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. [31] 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 educate and inform house owners on home energy technologies.

1.3 Research questions and aims

The following research question was raised initially to guide the study:

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

As the research progresses, the second question was raised:

- **How to develop effective explanations that build trust for a recommender in supporting households making sustainable decisions?**

The aim of this study is to address the information gap and support house owners in their decision-making process regarding the adoption of clean energy and energy-efficient technologies.

This thesis seeks to contribute to the HCI community by offering insights into the design and development of personalised and professional home energy system recommendations and their effectiveness in promoting the adoption of those technologies. Overall, the findings of this thesis hopefully can inform the development of future HCI interventions to address environmental challenges.

Chapter 2

Methodology

The study uses Design Case Studies [41] as the research framework.

2.1 Literature review

A comprehensive review of the literature aims to gain a thorough understanding of the current state of energy policies, as well as the importance of promoting energy efficiency at the household level.

2.2 Secondary research

Secondary research is then conducted to explore the motivators that influence households' investment decisions regarding energy technologies. This research involves analysing existing surveys to identify key factors driving households to make investment choices related to energy technologies. Special attention is given to financial considerations.

2.3 Investigation of field applications

The phase of the study concerning the investigation of field applications primarily focuses on exploring and examining practical strategies and approaches used to educate households about energy technologies. The objective is to identify effective methods that can be employed to assist households in making informed decisions regarding energy-efficient technologies. However, given the limited availability of successful initiatives in this area, alternative options such as energy audits and academic models are being explored.

Chapter 3

Pre-study

3.1 Motivators for investment decisions

The attitudes and perspectives of users regarding energy efficiency, particularly in relation to home energy systems, were investigated through a comprehensive survey conducted by Palmer et al. [31] 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.

3.2 Social practices

Currently, homeowners have limited avenues to access information about home energy systems. Presently, individuals seeking such information typically have two options. One is visiting the official websites of specific technology providers or physically visiting nearby stores that specialise in the sale of one or various energy technologies. However, this necessitates a prerequisite understanding 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. An alternative approach is through 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 in some cases, advice on suitable energy technologies to optimise energy efficiency.

3.3 Research-based models

Several research-based models furnish evidence to aid homeowners in making informed decisions regarding home energy systems.

3.3.1 PVGIS online tool

PVGIS [9] 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 3.1, 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.

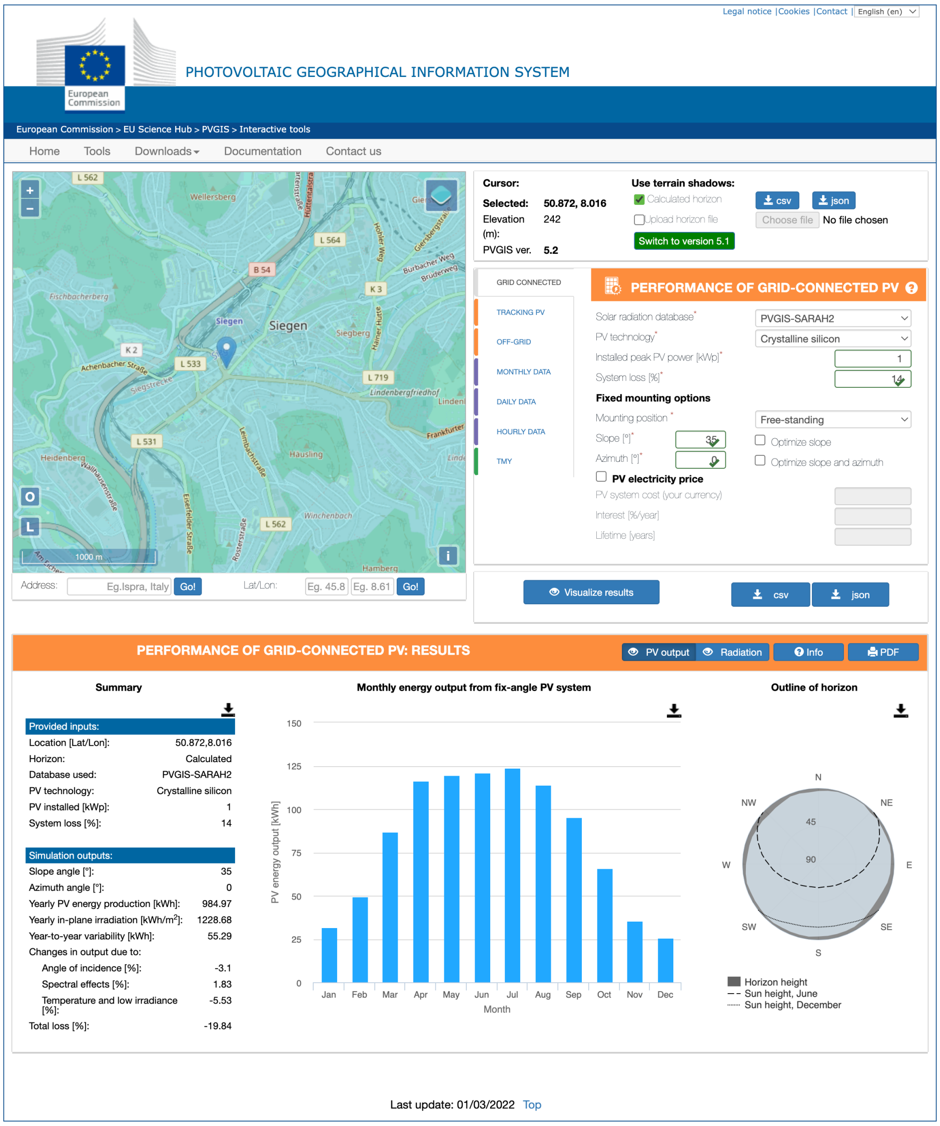

Figure 3.1: Screen of PVGIS online tool

3.3.2 FLEX models

The FLEX models [42], 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 3.2. Consequently, it offers a comprehensive evaluation of the energy consumption of a representative building. Moreover, the tool can be used to predict energy bills, enabling comparisons of energy expenses associated with different technology adoptions.

As mentioned, existing studies identify financial aspects as the primary factors guiding homeowners' decisions when contemplating upgrades to their home energy systems. In light of this, the FLEX models emerge as an ideal tool for assisting homeowners in determining which technologies to invest in. These models encompass numerous factors, enabling relatively accurate predictions of energy consumption and associated energy bills. Therefore, the FLEX models can be utilised to provide valuable insights to homeowners seeking to make informed decisions about their system investments.

[1] https://newtrends2020.eu/

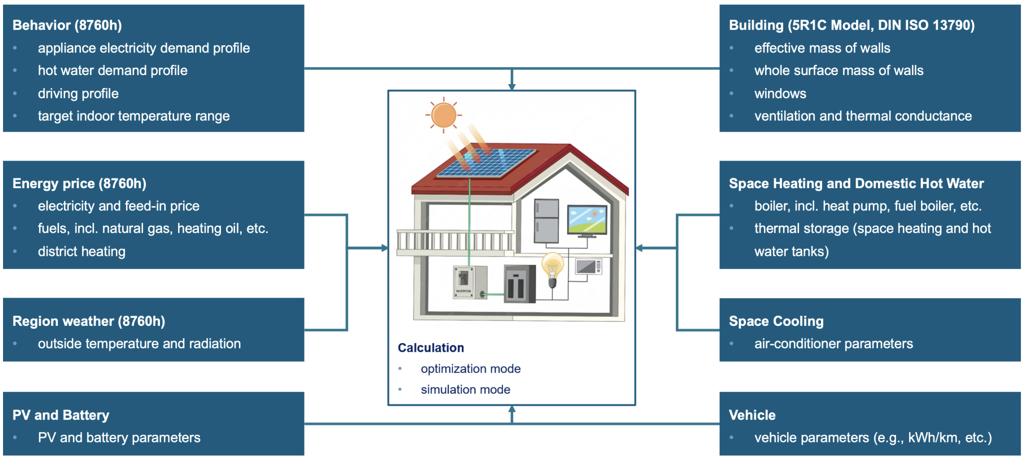

Figure 3.2: Model structure for individual households

Chapter 4

Design

In order to bridge the information gap regarding home energy systems, this study aims to provide households with knowledge of available technologies in the market. Based on the findings from pre-study and to address the potential issue of information overload, the study proposes a home energy system recommender to present households with a tailored selection of technologies that better fit their unique home situations. For instance, by learning the location of the house, in order to estimate the amount of sunlight it is likely to receive over the course of a year, to evaluate whether installing a PV system would be a viable and economic way for the household. The learning theory 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 home energy technologies. Meanwhile, nudging house owners towards making informed decisions.

4.1 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 simulated 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.

4.2 Input to the recommender

4.2.1 Household profiles

The concept of household profile has been developed to gain insights into 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.* By creating such a profile, a comprehensive understanding of the household's situation can be attained, enabling the offering of more tailored and effective recommendations.

The categories were inspired by the FLEX models [42]. The models take a set of variables into account when simulating, they can be divided into

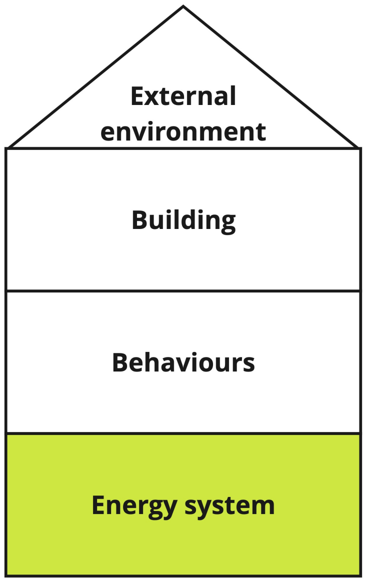

Figure 4.1: Household profile

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.

4.2.2 Households data collection

While collecting more detailed data leads to increased accuracy in simulations in FLEX models, it is crucial to maintain user-friendly by not overwhelming users with excessive information requests. To strike a balance, a set of 13 questions (as outlined in Table 4.1) was developed to gather relevant information for household profile analysis. Using the provided user answers, additional specific information can be inferred. For example, by inputting the construction period of the house, corresponding details such as building materials and sizes can be assumed.

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: Survey questions

To further 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.

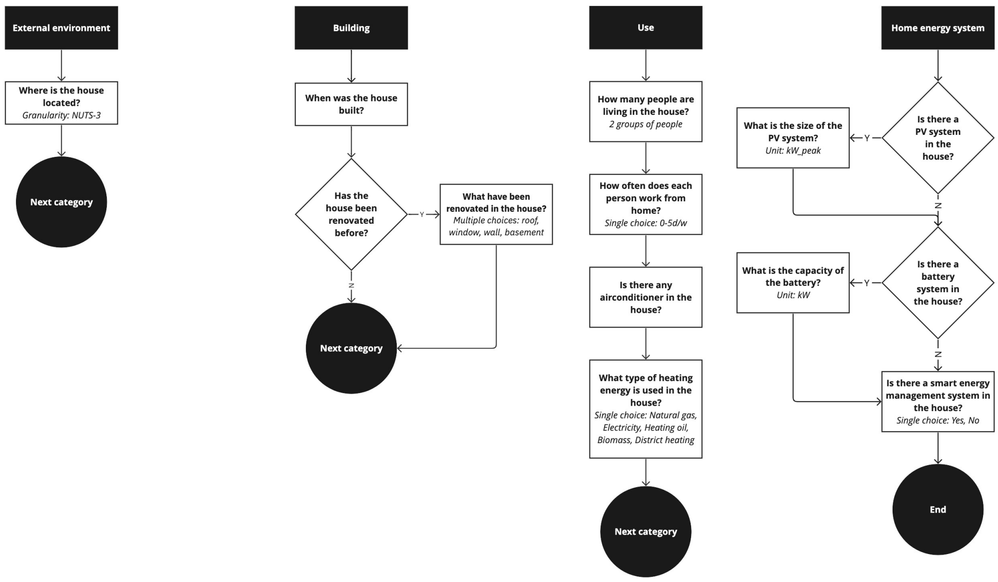

Figure 4.2: Question decision trees

4.3 Output from the recommender

4.3.1 Recommendations

A sustainable home energy system should prioritise *energy-efficiency, reducing dependence on non-renewable fossil fuels, and lowering overall energy costs*. All recommendations aligned with these fundamental principles, aim to promote sustainable energy practices while also reducing household energy costs. The energy technologies recommended to users are for generating renewable energy, managing energy usage, and improving energy efficiency. For example, the recommended technologies include the PV system, the battery system, the SEMS system, HP, and house renovation, as they contribute to energy efficiency improvements. 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, our system identifies configurations that can lead to lower energy bills compared to the user's current situation. However, to avoid overwhelming users with an excessive number of recommendations resulting from the various arrangement combinations of technologies, particularly when accounting for different sizes, we aim to provide recommendations that offer tangible financial benefits to users. To achieve this, we considered three distinct perspectives. Firstly, we present the most techno-economic solution, which compares the annualised investment costs and the annual energy cost to determine the configuration that yields the highest financial advantage for households. Secondly, we offer the solution with the highest energy bill savings, disregarding investment costs, since investment costs may vary across different areas, and there is a possibility that users can find cheaper options for implementing the recommended technologies. This allows users to gain insights into the most energy-efficient configurations available for their homes. Lastly, we provide the solution with the lowest investment cost, enabling users to identify a cheaper step towards enhancing their home energy system. In addition, we empower users to customise the energy system according to their specific needs and preferences in the detail page. Presenting recommendations from three perspectives while allowing customisation is believed to be an appropriate balance. The efficacy of this approach will be evaluated during the testing phase.

4.3.2 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 [30], previous studies have identified ten purposes of explanations, including *transparency, effectiveness, trust, prersua-*

siveness, 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.

Trust By offering more detailed simulated 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.

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 [35], 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. 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. [26] 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 the technology products that should be installed or upgraded in their homes. Additionally, it provides information on the corresponding yearly energy bills associated with each configuration. 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 the potential improvements that can be achieved in terms of energy efficiency and cost savings.

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.

The third level of explanation This level of explanation focuses on providing cognitive knowledge 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.

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 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 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.

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.

Presetation

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, in the form

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

Technology	Initial investment (€)	Life (year)	Annualised cost (€)	Ref
PV system	1200/kWp	15	115.61/kWp	[5]
Battery system	428.57/kW h	15	41.29/kW h	[5]
SEMS	1000	15	96.34	[5]
HP	/	/	900	[6]
Building renovation	/	/	2000	[21] [20]

Table 4.3: Investment costs of different technologies

of textual descriptions, are utilised to provide detailed information about technology functionalities and costs. Charts are employed to present energy consumption data in a visual format. 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.

4.4 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 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.

4.5 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 4.3) 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 introduction 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.

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

A 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.

Data privacy information 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.

Involvement of organisations 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.

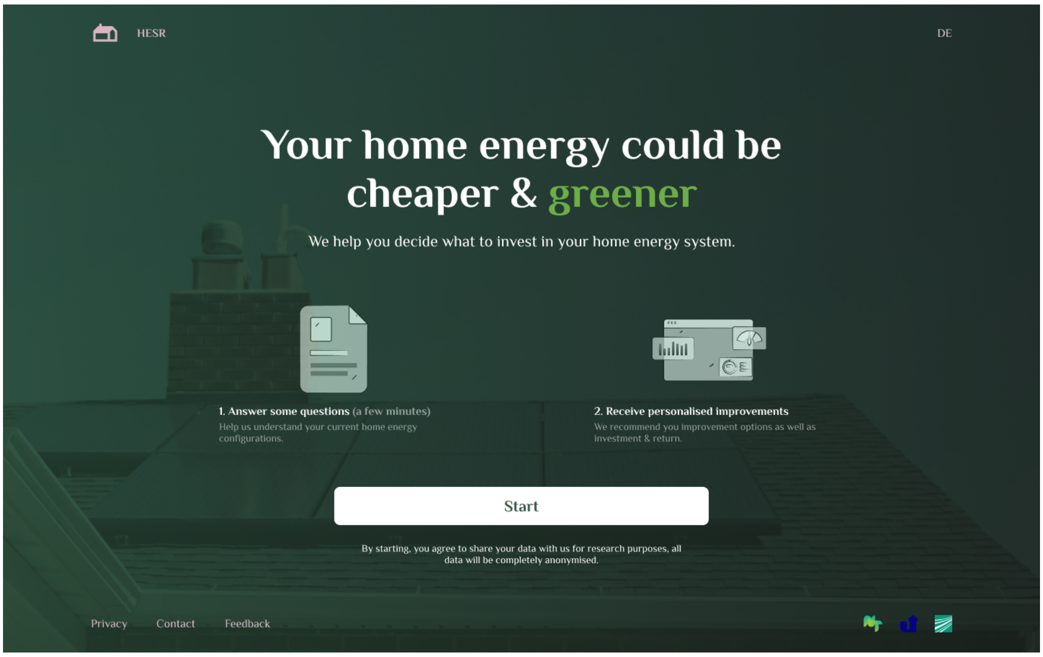

Figure 4.3: Homepage

Questionnaire

The questionnaire page (Figure 4.4) 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:

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.

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

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

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

"I Don't Know" option Users are provided with an option to select "I don't know" if they are unsure about a particular question.

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.

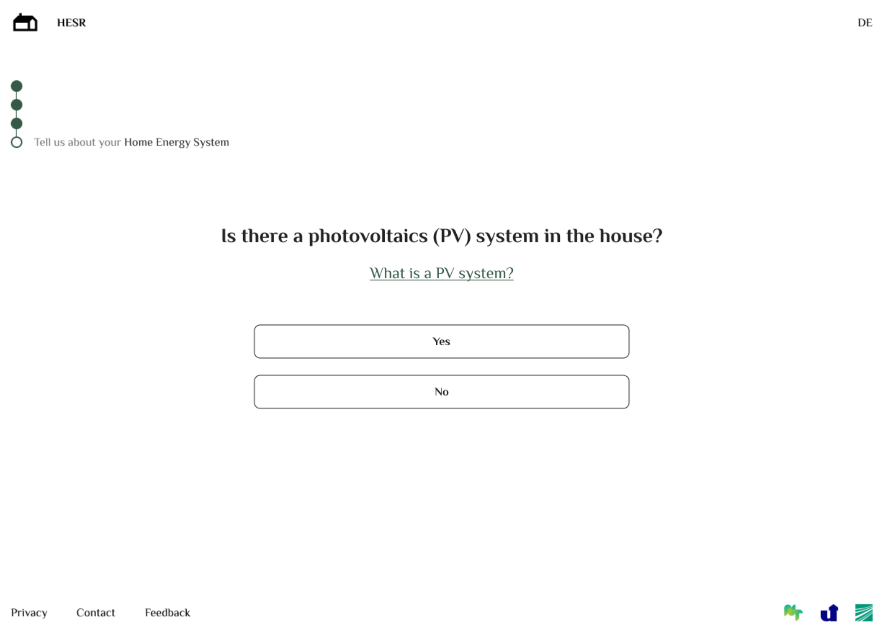

Figure 4.4: Questionnaire

Recommendation

The recommendation page (Figure 4.5 and 4.6) 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.

Flexible orders The system allows for different ways of presenting 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.

Simulation

The simulation page (4.7) aims to provide users with more detailed explanations about the recommended options.

Data visualisation It utilises data visualization 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.

4.6 Usability testing

For a first roud of evaluation, a user testing session was conducted with a total of 5 participants. The primary focus of this testing round was to assess the usability of the service before proceeding with the actual coding and implementation of FLEX models. The goal is to ensure that the service meet the usability requirements and to gather initial feedback on the explainability of the recommendations provided.

4.6.1 Participants

The 5 participants selected for the testing session were primarily 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.

4.6.2 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 [38]. 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?
- 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?

4.6.3 Analysis of usability testing

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.

4.7 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.

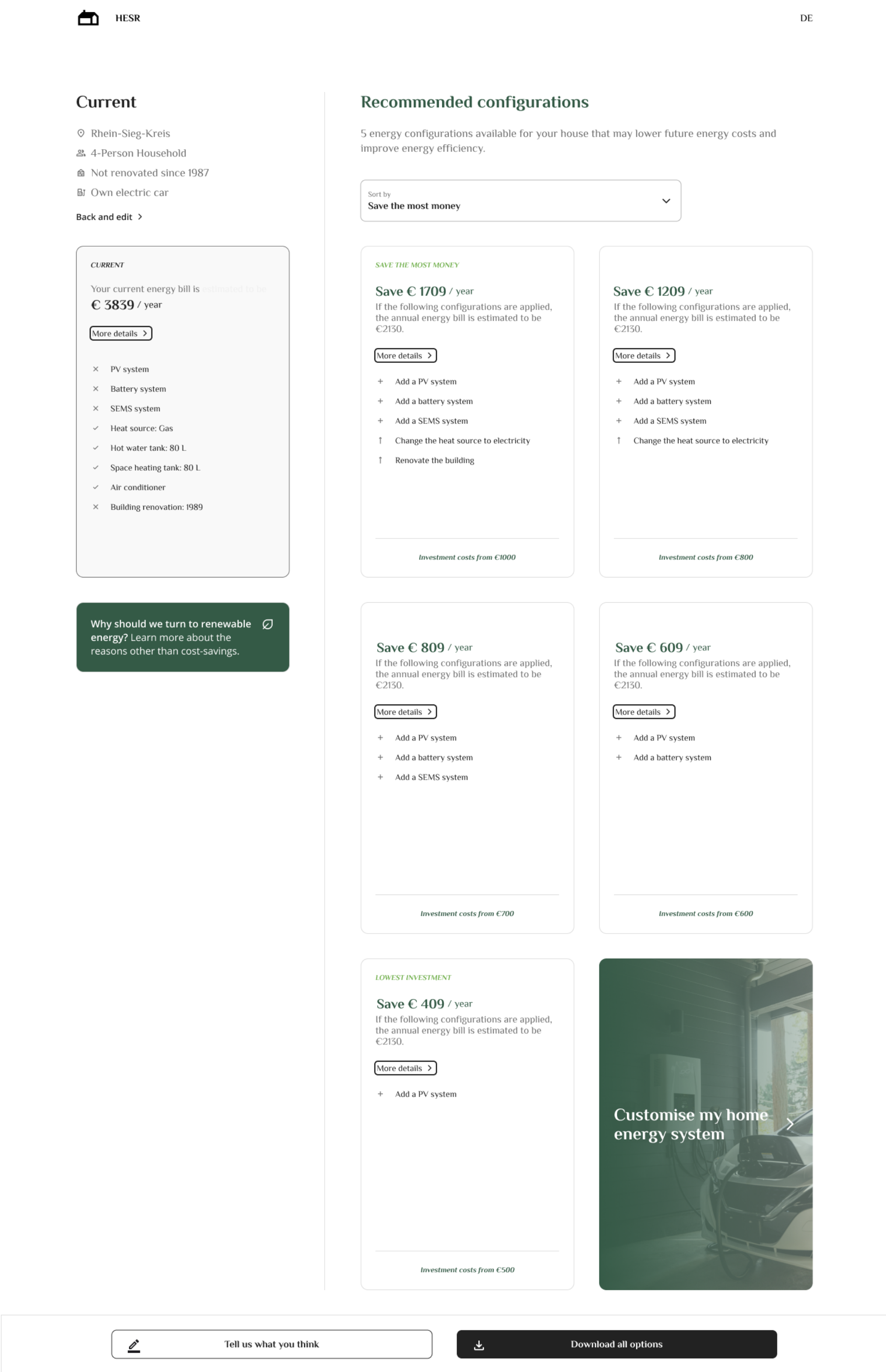

Figure 4.5: With recommendations

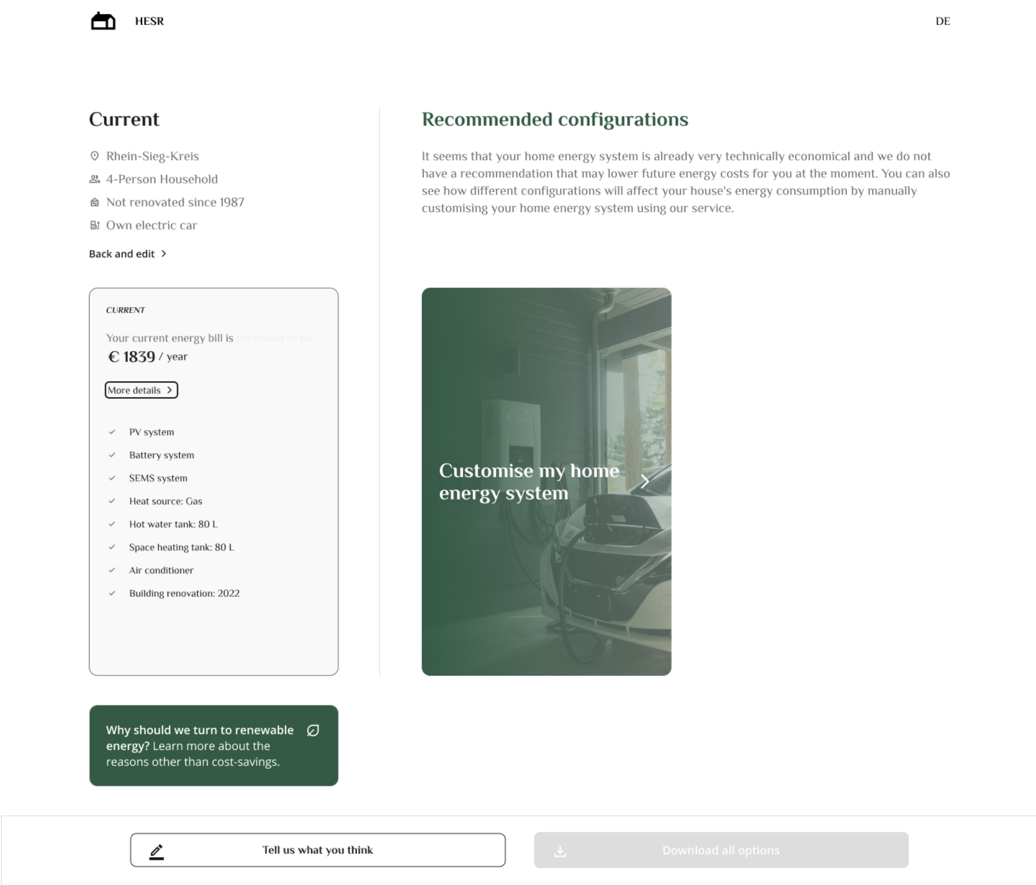

Figure 4.6: No recommendation

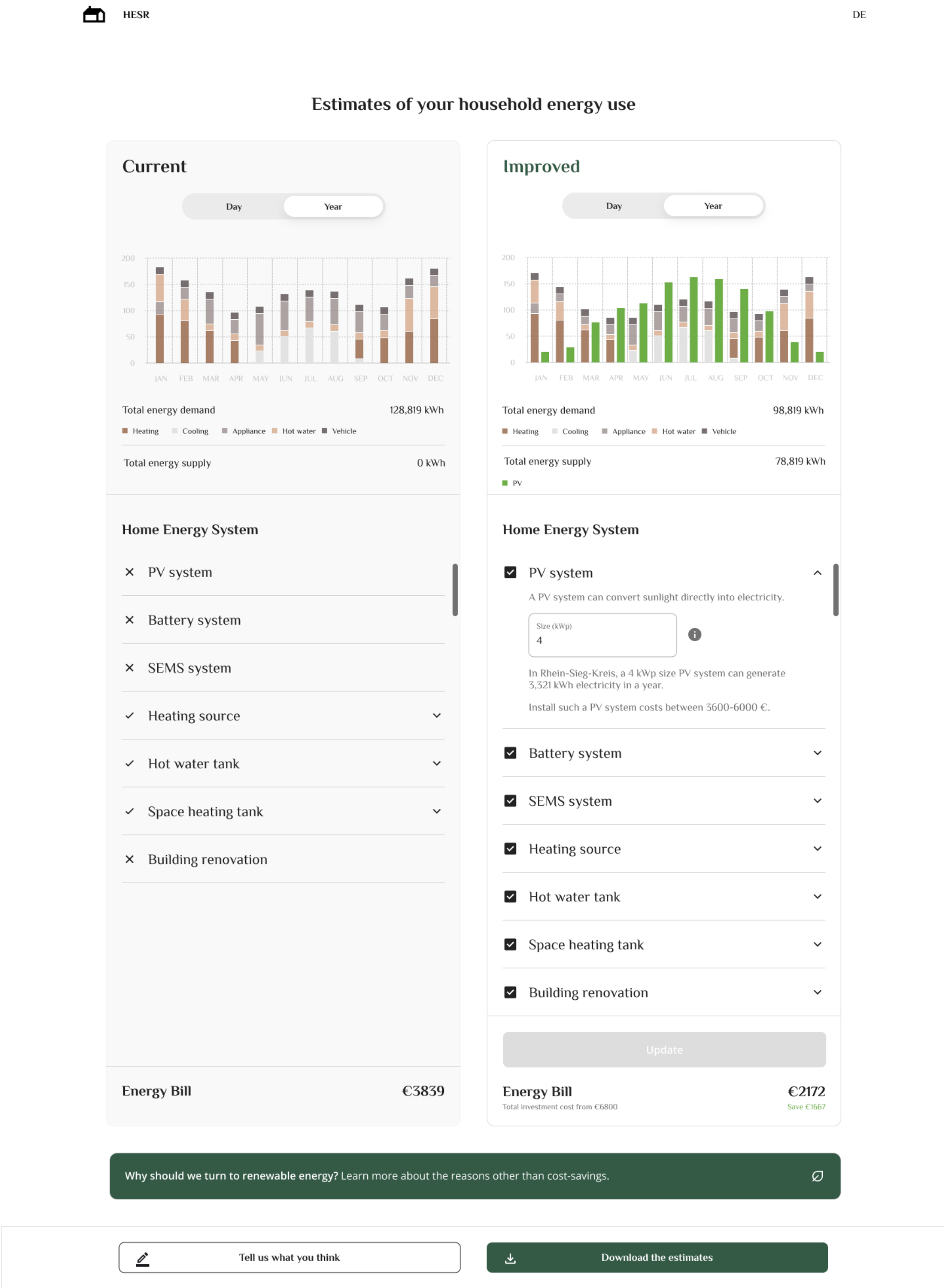

Figure 4.7: Simulation page

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 processing and analysis of data using the FLEX models.

5.1 Frontend

The frontend of the web application is responsible for creating an engaging and user-friendly interface using HTML, CSS, and JavaScript. These technologies work together 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 Survey

To incorporate surveys into the web application, we integrated SurveyJS, an open-source JavaScript form builder library. 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 [17]. However, we encountered difficulties in building multiple columns using Google Charts. As a result, we switched to Highcharts [19], another powerful charting library written in JavaScript.

5.2 Backend

The backend of the web application utilises Flask, a Python-based web framework, 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 7 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 design

The API design for the service follows a RESTful architecture and adheres to the JSON schema presented in this section.

5.2.2 JSON Schema Documentation

This JSON schema defines the structure and properties of a household's energy system and recommendation.

Household's energy system and recommendation

Properties

The documentation consists of three main components: profile, current, and recommendation as displayed in table 5.1.

Name	Type	Description	Required	Default value
profile	object	An object describing the house's location and number of people.	Yes	-
current	object	An object describing the house's current energy system configurations, energy data, and costs.	Yes	-
recommendation	array	A list of recommended configurations that improve the house's energy efficiency.	Yes	-

Table 5.1: Properties

Properties of profile

As table 5.2 shows, the profile component provides information about the house's location and the number of people residing in it. It includes properties such as location and person.

Properties of current

The current component describes the house's current energy system configurations, energy data, and costs. It consists of two properties: config and energy_data. See table 5.3.

Name	Type	Description	Required	Default value
location	string	The location of the house.	Yes	-
person	integer	The total number of people residing in the house.	Yes	-

Table 5.2: Properties of profile

Name	Type	Description	Required	Default value
config	object	An object describing the house's current energy system configurations.	Yes	-
energy_data	object	An object describing the energy demand, PV generation, and energy cost.	Yes	-

Table 5.3: Properties of current

Properties of config

The config property, as shown in table 5.4, captures the current energy system configurations, including parameters such as pv_size, battery_capacity, sems, heating_system, heating_system_type, and building_renovation.

Name	Type	Description	Required	Default value
pv_size	integer	Determine the size of the PV system.	Yes	-
battery_capacity	integer	Determine the capacity of the battery system.	Yes	-
sems	boolean	Determine the state of a SEMS system.	Yes	-
heating_system	boolean	Determine the state of the heating system used.	Yes	-
boiler_type	string	Determine the type of heating system used.	Yes	-
building_renovation	boolean	Determine the state of the renovation.	Yes	-

Table 5.4: Properties of config

Properties of energy_data

The energy_data property contains data related to energy demand, PV generation, and energy cost. It includes properties like energy_demand, energy_generate, heating, cooling, appliance, hotwater, pv, and energy_bill_year. See table 5.5.

Properties of recommendation

The recommendation component represents a list of recommended configurations that can improve the house's energy efficiency. As listed in table 5.6, each recommendation includes properties similar to the config and energy_data properties in the current component. Additionally, it includes an investment_cost property indicating the annualised investment cost for the recommended configuration.

Example JSON data

```
"energy_data": {
    "energy_demand": 0,
    "energy_generate": 0,
    "heating": [0,0,0,0,0,0,0,0,0,0,0,0],
    "cooling": [0,0,0,0,0,0,0,0,0,0,0,0],
    "appliance": [0,0,0,0,0,0,0,0,0,0,0,0],
    "hotwater": [0,0,0,0,0,0,0,0,0,0,0,0],
    "pv": [0,0,0,0,0,0,0,0,0,0,0,0],
    "energy_bill_year": 0
},
```

The JSON data example can be found in the appedix D.

5.2.3 Endpoint

The API exposes 3 endpoints to retrieve data, they are scenario_id, recommendations and energy_data. The endpoints accept HTTP GET requests and returns JSON responses.

Name	Type	Description	Required	Properties in Database
energy_demand	integer	The total energy demand in a year.	Yes	-
energy_generate	integer	The total energy generated by PV in a year.	Yes	-
heating	array	The energy demanded for heating in the house for each month.	Yes	E_Heating_HP_out + Q_HeatingElement
cooling	array	The energy demanded for cooling in the house for each month.	Yes	E_RoomCooling
appliance	array	The energy demanded by all appliances in the house for each month.	Yes	BaseLoadProfile
hotwater	array	The energy demanded for hot water in the house for each month.	Yes	E_DHW_HP_out
pv	string	The energy generated from PV in the house for each month.	Yes	PhotovoltaicProfile
energy_bill_year	integer	The total yearly energy cost.	Yes	-

Table 5.5: Properties of energy_data

Name	Type	Description	Required	Default value
config	object	An object describing the recommended energy system configurations.	Yes	-
energy_data	object	An object describing the energy demand, PV generation, and energy cost.	Yes	-
investment_cost	integer	The annualised investment cost for the recommended configuration.	Yes	-

Table 5.6: Properties of recommendation

Chapter 6

Evaluation

In this chapter, we present the evaluation of our IT artefact. The evaluation study focuses on two main aspects. Firstly, we assess the effectiveness of the explanations provided to users in helping them understand why specific configurations were recommended for their home energy systems. Secondly, we evaluate whether the information presented through the explanations has an impact on users' attitudes, such as increased awareness of energy-efficient technologies or a stronger inclination to adopt them.

As highlighted in Nunes and Jannach's summary [30], 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 assessing any changes in their attitudes, 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 6 participants in the South Germany region. While the sample size was small, qualitative studies provide valuable insights into rusers' perceptions, attitudes, and experiences.

6.1 Semi-structured interviews

The interview will follow the structured format to gather insights from the participants.

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 (approximately 40 minutes) 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 energy systems.
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. Allow participants to utilise the service using a laptop.
7. Once the participants have interacted 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 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. Additionally, we extended our recruitment efforts to colleagues within Fraunhofer ISI.

The interview invitation is:

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 40-minute interview for our web service developed in collaboration with the University of Siegen. Don't miss out on the opportunity to test our web service, which provides personalised techno-economic investment recommendations tailored to your unique home situation. 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 remotely for your convenience. 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 this exciting opportunity to collaborate on our project!

Every participant took part in the evaluation signed a consent form (Appendix E) before starting.

ID	Gender	Age	Location	Background
P1	M	60	Germany	Construction

Table 6.1: Participants

Goals

- Evaluate the effectiveness of explanations in helping users understand the rationale behind recommended configurations for their home energy systems.
- Assess the impact of the provided information on users' attitudes, including increased awareness of energy-efficient technologies and a higher propensity to adopt them.

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. 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 a 30-minute 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, explainability, attitude change, 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	
	Gender
	Age
Demography	Educational background

	Occupation Knowledge and interest in AI Knowledge and interest in the energy domain
Altitudes	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	
Altitudes	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?

Explainability

	Do you trust the recommendations? Why or why not? What factors contribute to your trust or lack of trust in the recommendations? 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 truly 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 [34] 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.

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

Table 6.4 summarises the participants' overall knowledge and interest in AI and energy, as well as their perspective on the altitude change and trust in the recommendations following their use of the service. In addition, all transcripts can be found in the appendix F.

ID	Interest in AI	Interest in energy	Altitude change	Trust
PA	No	Yes	No	Yes
PB	No	Yes	No	Yes

Table 6.4: Participants' perceptions about AI and energy

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 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.

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 1 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.

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.
Continued on next page	

Table A.1 – continued from previous page

Category	Data
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.

Continued on next page

Table A.1 – continued from previous page

Category	Data
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.
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.

Continued on next page

Table A.1 – continued from previous page

Category	Data
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

Usability 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 visualization! 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

Example JSON Data


```
{
  "profile": {

    "location": "DE",
    "person": 3

  },

  "current": {

    "config": {

      "pv_size": 0,
      "battery_capacity": 0,
      "sems": false,
      "heating_system": true,
```

```
    "heating_system_type": "heating oil boiler",
    "building_renovation": true

  },

  "energy_data": {

    "energy_demand": 0,
    "energy_generate": 0,
    "heating": [0,0,0,0,0,0,0,0,0,0,0,0],
    "cooling": [0,0,0,0,0,0,0,0,0,0,0,0],
    "appliance": [0,0,0,0,0,0,0,0,0,0,0,0],
    "hotwater": [0,0,0,0,0,0,0,0,0,0,0,0],
    "pv": [0,0,0,0,0,0,0,0,0,0,0,0],
    "energy_bill_year": 0

  },

},

"recommendation": [{

  "config": {

    "pv_size": 0,
    "battery_capacity": 0,
    "sems": false,
```

```
      "heating_system": true,
      "heating_system_type": "heating oil boiler",
      "building_renovation": true

    },

    "energy_data": {

      "energy_demand": 0,
      "energy_generate": 0,
      "heating": [0,0,0,0,0,0,0,0,0,0,0,0],
      "cooling": [0,0,0,0,0,0,0,0,0,0,0,0],
      "appliance": [0,0,0,0,0,0,0,0,0,0,0,0],
      "hotwater": [0,0,0,0,0,0,0,0,0,0,0,0],
      "pv": [0,0,0,0,0,0,0,0,0,0,0,0],
      "energy_bill_year": 0

    },

    "investment_cost": 0

  }]
}
```

Appendix E

Consent form

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

Principal Investigator: Yanwei Miao

Affiliation: Siegen University, The Fraunhofer Institute for Systems and Innovation Research

Date:

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:

Participant Signature:

Date:

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

Appendix F

transcription

Participant B

Miao, Yanwei 00:00:00.739 – 00:00:15.500
Okay, I think you have received the information that it's recording right now and for your demographical information, I would like to ask about your gender.

Participant B 00:00:16.100 – 00:00:20.580
A male.

Miao, Yanwei 00:02:17.700 – 00:02:20.860
Do you mind letting me know your age?

Participant B 00:02:20.940 – 00:02:22.700
30.

Miao, Yanwei 00:02:24.420 – 00:02:29.700
And your educational background.

Miao, Yanwei 00:02:40.100 – 00:02:43.300
And like, what, what did you study, what is your subject?

Participant B 00:02:43.340 – 00:02:51.100
So I started geography, which is the main topic and it was about environmental and climate change.

Miao, Yanwei 00:02:55.460 – 00:02:59.020
And your occupation right now.

Participant B 00:03:00.060 – 00:03:03.740
So I'm working for the ISI, It's like.

Participant B 00:03:06.740 – 00:03:09.540
I don't know the English expression actually, so it's wissenschaftliche Mitarbeiter.

Miao, Yanwei 00:03:15.660 – 00:03:23.540
Okay, that's, that's fine. And May, I know whether you have a bit of knowledge or interesting, AI.

Participant B 00:03:25.100 – 00:03:28.820
The first part of the thing was, was a little bit.

Miao, Yanwei 00:03:31.420 – 00:03:35.780
Do you have any knowledge or do you have any interest in AI?

Miao, Yanwei 00:03:37.060 – 00:03:38.340
Artificial intelligence.

Participant B 00:03:39.220 – 00:03:49.220
Not really no, not more than like, the, the basic interest in I just tried out the new tools which are available, but not more than that.

Miao, Yanwei 00:03:49.220 – 00:03:55.980
Okay, and do you have any knowledge or interest in the energy domain?

Participant B 00:03:57.180 – 00:03:58.780
Since I.

Participant B 00:04:00.180 – 00:04:14.820
A lot of time into researching for my masters thesis I have a little bit experience in the field of district heating and, and a wind power as I worked as a wind power company before.

Miao, Yanwei 00:04:15.460 – 00:04:16.579
Okay.

Miao, Yanwei 00:04:19.299 – 00:04:38.500
Sounds good, thank you. So maybe also I would like to know something about your attitudes towards energy efficient technologies. Have you heard of energy efficient appliances or renewable energy technologies for households.

Participant B 00:04:44.300 – 00:04:56.420
So you mean like installation measures or new technologies regarding eat production or on water production. Something like that, or what do you mean?

Miao, Yanwei 00:04:56.500 – 00:05:00.900
Yes, basically like, very general, have you ever heard of any.

Miao, Yanwei 00:05:03.460 – 00:05:13.660
And have you ever considered implementing energy efficient technologies such as solar panels or smart thermostats.

Participant B 00:05:15.220 – 00:05:34.180
We're talking about installing smart term as we also have an electric car, we would like to use it to better plan the charging procedure, and then we also are talking about getting our roof insulated better insulation.

Participant B 00:05:34.940 – 00:05:41.220
It's hardly insulated now, but we want to increase the installation and.

Participant B 00:05:41.980 – 00:05:47.500
Also thinking about buying a footable tank.

Participant B 00:05:49.740 – 00:05:56.860
Tags, but the lack of money right now can afforded, but it's, we have plans for it.

Miao, Yanwei 00:05:57.220 – 00:06:06.580
Sounds good, and what is your understanding regarding the benefits of energy efficient technologies.

Participant B 00:06:10.100 – 00:06:25.940
Reduction of the needs. So we, we would need less energy consumed and obviously also for, for example, the roof insulation, it's in the summertime or during the winter, it's less.

Participant B 00:06:27.340 – 00:06:32.420
Strong changes in the room temperature, which is beneficial as well.

Miao, Yanwei 00:06:33.780 – 00:06:39.140
And do you know climate change And why is it important to individuals?

Miao, Yanwei 00:06:42.660 – 00:06:55.060
Climate change and why is climate change important for individuals to save energy or utilize renewable energy resources.

Participant B 00:06:55.820 – 00:07:15.940
You mean why it is important to everybody, and why everybody should, I think everybody should do what, what he or she can do in order to reduce their demand so that in, in total, the demand decreases and the targets, which are set for.

Participant B 00:07:16.140 – 00:07:19.780
For the entire community can be reached so...

Participant B 00:07:20.660 – 00:07:23.220
Play its small part. I think.

Miao, Yanwei 00:07:25.700 – 00:07:27.700
Know a lot about that.

Miao, Yanwei 00:07:29.380 – 00:07:38.180
Sounds good, so I, I've already finished the pre-questions and now I will send you a link.

Miao, Yanwei 00:07:39.860 – 00:07:44.100
You should have received a link in our chat now.

Miao, Yanwei 00:07:46.660 – 00:07:50.500
If you click the link and then you are landing our service.

Miao, Yanwei 00:07:53.060 – 00:08:05.220
And do you mind to share your screen so that I can see how you operate through the website, but if you don't want to eat, you can also just say no, and just let me know which step you are.

Miao, Yanwei 00:08:59.220 – 00:09:03.540
As long as it's comfortable for you to see, then it's fine.

Participant B 00:09:04.740 – 00:09:06.580
Okay, so.

Miao, Yanwei 00:09:09.860 – 00:09:10.500
You can think out loud.

Miao, Yanwei 00:09:11.900 – 00:09:14.340
When you are navigating through it.

Participant B 00:09:14.380 – 00:09:22.660
Okay, so, so what shall I look for shall. I look for like the UI or what, what is the main topic to look at?

Miao, Yanwei 00:09:23.300 – 00:09:25.100
Everything basically.

Participant B 00:09:25.300 – 00:09:25.860
Everything.

Miao, Yanwei 00:09:26.500 – 00:09:30.220
You can just share any thoughts when you are navigating.

Participant B 00:09:30.460 – 00:09:34.780
Great, so I like the look, it's really clean. That's the first impression.

Participant B 00:09:54.020 – 00:09:56.780
So I just need to select.

Participant B 00:10:01.700 – 00:10:07.620
So I think it's pretty straightforward. You, there's not much going on on the screen. I like that.

73 Participant B 00:10:40.660 – 00:10:42.100
Okay, so.

Participant B 00:10:48.340 – 00:10:52.580
Okay, so what's, what's the screen about?

Miao, Yanwei 00:11:02.460 – 00:11:07.420
You can ask me if you think you don't understand which part.

Participant B 00:11:07.540 – 00:11:12.620
So I, I will just click here to see more details how this calculated.

Participant B 00:11:16.500 – 00:11:17.940
Maybe I just.

Participant B 00:11:36.980 – 00:11:41.700
It's this for, for, it's for.

Participant B 00:11:42.780 – 00:11:47.780
An energy build, so this is for, and electricity.

Miao, Yanwei 00:11:50.420 – 00:11:52.980
You mean the price, the total price price.

Participant B 00:11:53.020 – 00:11:53.620
Yes, yes.

Miao, Yanwei 00:11:53.940 – 00:11:59.380
For all the energy, your whole house could consume.

Participant B 00:12:00.820 – 00:12:01.940
So.

Participant B 00:12:04.260 – 00:12:06.660
And electricity might take.

Participant B 00:12:30.900 – 00:12:32.020
Yes, makes sense.

Participant B 00:12:39.060 – 00:12:41.060
So it's for.

Participant B 00:12:42.900 – 00:12:54.020
For electricity and, and leading. So I just just quickly checked, but it's, it's underestimating already price.

Participant B 00:12:58.060 – 00:13:09.140
Yeah, but I think it's because we have electric car and it doesn't ask if we have an electric car in charge at home. So our electricity Bill is alone is really high. so.

Participant B 00:13:10.420 – 00:13:14.220
Do not have then fuel costs other than the electricity.

Participant B 00:13:16.180 – 00:13:26.500
So maybe it could ask for a car if, if someone has a car, then should have a higher demand for electricity.

Participant B 00:13:52.020 – 00:14:00.140
Already it was not not that much for this. I only have the numbers for last year, so.

Participant B 00:14:06.740 – 00:14:09.300
It was like, they had electricity Bill of.

Participant B 00:14:14.580 – 00:14:19.500
Three thousand, six hundred, but that's only electricity.

Participant B 00:14:21.500 – 00:14:22.820
Also, gas.

Participant B 00:14:25.340 – 00:14:31.300
Whether he was one thousand eight hundred, so.

Participant B 00:14:55.380 – 00:15:00.060
Okay, and then on the right side, you see, I can see some suggestions.

Participant B 00:15:03.940 – 00:15:05.940
Let me check. Let's see.

Participant B 00:15:10.100 – 00:15:20.980
Annualized cost, okay, and does it also show, like total costs or it like the total investment costs.

Participant B 00:15:33.900 – 00:15:35.700
Yeah, that's good.

Participant B 00:16:33.940 – 00:16:39.660
IZED investment costs of two thousand something. Yes, so I would.

Participant B 00:16:41.660 – 00:16:44.820
In total, I would pay like a hundred more.

Participant B 00:16:45.860 – 00:16:46.100
Okay.

Participant B 00:17:13.740 – 00:17:24.500
Or will there be the, or is there going to be the opportunity to enter my own figures, like, if I- if I see, okay, this doesn't fit perfectly...

Participant B 00:17:25.339 – 00:17:30.260
Can I then alter the estimations to my demand, for example.

Miao, Yanwei 00:17:30.900 – 00:17:38.580
And you can click the more detail on the recommendation cards if you want to like, see one of these.

Participant B 00:17:38.580 – 00:17:39.220
Oh, okay.

Participant B 00:17:50.740 – 00:17:53.540
And you also program this website.

Participant B 00:17:57.780 – 00:18:00.980
It's really nice. I like, it's really clean.

Miao, Yanwei 00:18:03.580 – 00:18:06.100
Very happy, it's my first.

Participant B 00:18:06.260 – 00:18:08.980
No, I can. Yeah, I can.

Participant B 00:18:09.940 – 00:18:12.500
For example, take this away and then.

Participant B 00:18:13.820 – 00:18:14.940
Okay.

Participant B 00:18:48.340 – 00:18:50.300
Okay, that's cool.

Participant B 00:19:10.100 – 00:19:15.860
Yeah, I, I think this, this website looks as I said, it looks really good.

Participant B 00:19:19.700 – 00:19:26.740
That you can alter some things and, and see what it makes, what kind of differences it makes.

Participant B 00:19:34.420 – 00:19:42.220
That's really cool. And so what is, what is your plan going forward with this?

Miao, Yanwei 00:19:42.740 – 00:19:52.980
This is already actually.

Miao, Yanwei 00:19:53.860 – 00:19:55.100
The results.

Miao, Yanwei 00:19:58.100 – 00:20:01.940
Yeah, you've already reached the last phase.

Miao, Yanwei 00:20:03.860 – 00:20:20.500
Thank you, and there's actually one more page, but it, you, you didn't notice it, but it's fine. It's for like, yes, it's the green bar. It says why should we turn to renewable energy?

Participant B 00:20:21.640 – 00:20:24.440
Before it was on the first page as well.

Miao, Yanwei 00:20:24.680 – 00:20:27.880
Yes, but it.

Participant B 00:20:28.760 – 00:20:32.360
That's like a, like a FAQ for.

Participant B 00:20:33.640 – 00:20:35.080
Why it's important.

Miao, Yanwei 00:20:35.560 – 00:20:50.200
Yes, it's for people who may want to the energy technologies, but they, they might mainly focus on the financial aspect.

Miao, Yanwei 00:20:51.120 – 00:21:00.520
Provide a little bit more information regarding like climate change, so it's just, someone doesn't.

Participant B 00:21:03.720 – 00:21:05.200
That it's also.

Participant B 00:21:06.400 – 00:21:13.800
Issue of like the human society in its core and not only about the numbers.

Miao, Yanwei 00:21:17.160 – 00:21:25.520
But according to my research financial reason, it's still the main reasons for.

Miao, Yanwei 00:21:27.520 – 00:21:29.800
To choose their energy technologies.

Participant B 00:21:33.200 – 00:21:44.040
Especially in times where other energies are really expensive, it's, it would, or it could be a huge benefit to produce your own energy as well, and, and do.

Participant B 00:21:46.080 – 00:22:04.640
Something good with it as well. So I think it will always be, or it should be, maybe should be different than everybody should be doing it because it's better for the environment, but I think the, the main driver will still be the economics at the end.

Miao, Yanwei 00:22:09.720 – 00:22:14.120
You have seen everything from the website, then.

Participant B 00:22:16.200 – 00:22:17.320
Fully.

Participant B 00:22:18.640 – 00:22:25.000
Haven't come fully into it now, but I can, I can do it via the link again and play around with.

Miao, Yanwei 00:22:28.200 – 00:22:39.080
And now the port is eighty eighty, but maybe later we will remove the eighty eight port. We will make it global so that you don't need to type the eighty eighty in the end.

Miao, Yanwei 00:22:40.400 – 00:22:42.280
Flex model dot org.

Miao, Yanwei 00:22:44.200 – 00:22:46.680
And, but before.

Miao, Yanwei 00:22:48.760 – 00:23:08.400
There are still some more questions after you operate with the system. Okay, I would still like to ask some questions regarding your attitude. So firstly, like, how do you feel about the recommended recommendations provided.

Participant B 00:23:09.800 – 00:23:16.840
So, as I already said in the beginning, we already thought about applying some of those recommend.

Participant B 00:23:20.320 – 00:23:27.080
In a sense, like at the moment, they're just too expensive to, to afford to implement, but.

Participant B 00:23:29.120 – 00:23:47.040
Fact that you get to play around with them and maybe you can, you can then check which size and you should go for or you get an idea at least, and then you can take that idea and go and look for solutions like technical solutions, for example, for Bettery size and the, the perfect.

Participant B 00:23:48.840 – 00:24:06.120
Recommendation for someone who can really put it in your home and then get get some offers about that thing, and then you have a number in mind, what, what we expect, I think that's a really good overview, if you are just starting, it's like the first step is go there.

Participant B 00:24:08.080 – 00:24:13.800
What can I do and how much will it be? Roughly, that's really good like that.

Miao, Yanwei 00:24:14.520 – 00:24:30.440
And, and you said you were worrying because you were worrying about the financial aspect, but after you seeing some of the recommendations where it says actually you will pay less every year.

Miao, Yanwei 00:24:31.120 – 00:24:32.360
Comparing to the.

Participant B 00:24:32.480 – 00:24:38.760
Well, the electric car you pay, you have to pay a little upfront and then you save.

Participant B 00:24:40.080 – 00:24:53.000
I think still the, the thing is to invest the money in the first place, you, you need to have some money to do the to do, So, so I think that's still.

Participant B 00:24:54.160 – 00:25:00.520
A little prevents many people from doing it. I think so, maybe they're.

Participant B 00:25:01.360 – 00:25:04.880
Be more easier accessible.

Participant B 00:25:07.560 – 00:25:09.480
How to say bottom.

Miao, Yanwei 00:25:09.480 – 00:25:10.120
Well, the big.

Participant B 00:25:10.400 – 00:25:12.040
Support from the government for.

Participant B 00:25:13.320 – 00:25:13.960
Yeah, yeah.

Participant B 00:25:13.960 – 00:25:21.000
So that, that people can do it more easily or even can pay for it on a monthly basis or something like...

Participant B 00:25:21.640 – 00:25:27.840
And that way it would be easier for, for many people to do it.

Miao, Yanwei 00:25:28.680 – 00:25:37.000
Yes, you are right? And do you find the recommendations useful or valuable?

Participant B 00:25:39.120 – 00:25:49.160
And I also, yeah, as I said, I like how it's presented it also. I think it plays a huge role, how you get the information back if it's like.

Participant B 00:25:50.640 – 00:26:04.160
If it's not like providing a good overview and it's like, you have to search for the results, then it will be, it will not be used. So I really like it that it's really clean and lightweight so to say.

Miao, Yanwei 00:26:04.520 – 00:26:07.640
Thank you, so.

Miao, Yanwei 00:26:09.760 – 00:26:17.320
What factors influence your decision to adopt or reject the recommendations. I think you just answered that.

Miao, Yanwei 00:26:19.240 – 00:26:23.720
And, you know, why the recommendations were recommended to you.

Participant B 00:26:25.080 – 00:26:41.640
Yeah, it depends on the, on the situation of the home. What would be interesting for me, for example, be like, but that's, I think that's too too deep for for a website, which ones just to make some recommendations to.

Participant B 00:26:42.360 – 00:26:59.560
Give you information to start with. Would then be like you need to know. Okay, is my building really, is it an option would be able to put a system on it because of the shape of the roof and stuff like that, but.

Miao, Yanwei 00:27:06.000 – 00:27:07.880
More detailed information about.

Participant B 00:27:08.280 – 00:27:24.520
But I don't know how to apply to that website because then you would need to do them calculations on how your roof is suitable for a, for a photo TIG system and how much energy you could expect from it. For example.

Participant B 00:27:25.800 – 00:27:32.960
How large is the roof and what's the insulation and stuff? I think that's maybe out of scope.

Miao, Yanwei 00:27:33.480 – 00:27:47.560
No, actually the model it provides everything, but during our first version we didn't put so much numbers in it so much data that you cannot change or you can adjust.

Participant B 00:27:48.240 – 00:27:48.840
Yeah.

Miao, Yanwei 00:27:48.840 – 00:27:50.760
But that's possible.

Miao, Yanwei 00:27:51.560 – 00:27:53.960
Could be future work. Yes.

Participant B 00:27:53.960 – 00:27:55.080
So.

Miao, Yanwei 00:27:55.920 – 00:27:56.520
Consider.

Participant B 00:27:56.560 – 00:28:08.160
It's really interesting, like, if it develops into a one stop opportunity to do all your calculations there. I really think that's a great thing.

Participant B 00:28:09.560 – 00:28:16.360
I work with a software for district heat planning and they also tried.

Participant B 00:28:19.600 – 00:28:26.680
Also really accelerates how people approach that. So I think that's a good thing to develop stuff like that.

Miao, Yanwei 00:28:27.880 – 00:28:34.360
I also believe so, and so you, do you trust the recommendations.

Participant B 00:28:35.880 – 00:28:56.040
Since for, for example, the first thing I rec, I noticed is that the only based on your, some of your questions and then the estimations were quite accurate now leaving behind that didn't ask for the car and that's why the recommendations don't fit perfectly, but I think.

Participant B 00:28:56.160 – 00:29:12.680
They are quite good other than that, so that makes very good impression. must be a good model behind it. So I think it's, it's good. I couldn't click on the details page on that for that, but I would like to see.

Participant B 00:29:14.720 – 00:29:26.200
Behind it, so not not for an end user, I think not the real detailed calculations, but like, split into the numbers, but probably you have that as well. So.

Miao, Yanwei 00:29:26.760 – 00:29:34.440
You, you could also when you click the recommendation detail, you could also see the current data on the left side.

Participant B 00:29:34.720 – 00:29:37.000
Oh, okay, that was the current. yeah.

Miao, Yanwei 00:29:37.000 – 00:29:37.640
Yes, yes.

Miao, Yanwei 00:29:41.480 – 00:29:46.600
Yeah, there, there's sort of like a comparison with your current situation. Yeah.

Miao, Yanwei 00:29:47.400 – 00:29:58.800
It was my fault that I've, I've only put all the links on the right side. I forgot it. I mean, thank you for, for noticing that, and I, I need to adapt my usability.

Miao, Yanwei 00:30:02.840 – 00:30:08.680
I was considered also to be shown there of the current detail as well.

Miao, Yanwei 00:30:12.200 – 00:30:14.240
Yes, and.

Miao, Yanwei 00:30:15.520 – 00:30:20.680
What factors contribute to your trust or a lack of trust in the recommendations.

Participant B 00:30:24.060 – 00:30:30.460
So, yeah, as I said, in the first place, the numbers so that the estimations work, right? Quite correct. I think.

Participant B 00:30:32.460 – 00:30:42.620
That's the, the main reason why you can trusted if you, so, I mean, if you put in your personal data and then the calculation is quite accurate, then.

Participant B 00:30:43.540 – 00:30:52.860
Then you can rely on it in a sense that it will give you a recommendation that is not completely out of scope, like, then.

Miao, Yanwei 00:30:52.900 – 00:30:53.500
Then you can.

Participant B 00:30:53.780 – 00:31:13.980
A little more and as well, what contribute, what contributes I think is the, the periods of the website is really well programmed and it works quickly smoothly. So I think that's also a part that plays an important role if you are a consumer that looks at the page and if it's.

Participant B 00:31:14.060 – 00:31:31.900
Responsive if it's not like too many options, but you can go through it very quickly. So then you will do it more likely than going through a website which takes you like two hours to complete and you will, you will never do that. So, but.

Participant B 00:31:32.700 – 00:31:42.780
Fast and responsive and looks looks good and is experiment explanations that are understandable for everyone. I think that's.

Participant B 00:31:43.420 – 00:31:46.700
A good contribution as well to trust it.

Miao, Yanwei 00:31:47.380 – 00:31:51.020
Thank you is understandable all those information provided.

Participant B 00:31:52.380 – 00:32:12.220
Yeah, at least for me, it was, but I, I'm also a little bit into the topic so I think for, for someone who owns the house and thought about it a while and has some, some of the vocabulary down, I think then it's no issue. I don't know how it.

Participant B 00:32:12.860 – 00:32:17.340
For someone who has never been in touch with a topic. I don't know, but.

Participant B 00:32:18.260 – 00:32:22.020
Doesn't seem too over complicated to me.

Miao, Yanwei 00:32:23.100 – 00:32:30.140
Great and, and did the system provide enough information for you to understand the technologies. You think.

Participant B 00:32:30.780 – 00:32:50.620
There's more descriptive text. I, I really like that as well there. I think it's better to have a small or short descriptive text that mentions the main things and not too much detail because then it also could make people not read it at all. if it's too long.

Participant B 00:32:50.620 – 00:32:51.900
So I think.

Participant B 00:32:53.180 – 00:33:02.140
It's a good balance between a short text information and keeping people on track and to do it.

Miao, Yanwei 00:33:03.540 – 00:33:07.140
Do you mean having some short.

Miao, Yanwei 00:33:08.620 – 00:33:12.700
Generalized information as well for the current technologies.

Participant B 00:33:15.660 – 00:33:18.460
Sorry, I didn't get the first part.

Participant B 00:33:41.220 – 00:33:53.980
My case is not because I already looked into it, but yeah, as I said, for someone who didn't have any contact with the topic before it might be the case, I don't know.

Miao, Yanwei 00:33:57.180 – 00:34:14.460
And maybe do you have anything you would like to share this is the last question, like, besides what I have asked you any extra thoughts about the system or anything can be IMPRO.

Participant B 00:34:17.659 – 00:34:26.620
Yeah, as I said, only the thing that you might want to enter your own figures like your own.

Participant B 00:34:27.540 – 00:34:40.700
Or the, the last, if you have a utilities, Bill and, you know, your demand you could enter it so that would make the calculations even better. I assume. so I think that would be an option for someone who.

Participant B 00:34:41.460 – 00:34:45.940
Wants to deprint it, and maybe you can also.

Participant B 00:34:47.740 – 00:35:07.580
Some values for, for offers you got from, from a company, for example, who wants to, to build your photobal tax system or something like that. Maybe you can put it into that into your system as well. Maybe that is also a good thing, but I think that's more for the advanced US.

Participant B 00:35:07.780 – 00:35:10.780
Some sort of thing like you really want.

Participant B 00:35:14.220 – 00:35:18.980
Assimulation to the, to the most accurate point, maybe.

Miao, Yanwei 00:35:21.020 – 00:35:24.860
Maybe I'm trying to find out.

Miao, Yanwei 00:35:27.420 – 00:35:38.260
Thank you so much. These are all the info, all the questions and I, I think we are actually, I'm, I'm three minutes exceeding my.

Miao, Yanwei 00:35:39.620 – 00:35:44.340
But no, I'm sorry that I, I spent.

Miao, Yanwei 00:35:48.740 – 00:35:55.740
It's really very informative information that I get from you and I, I would really like to show my appreciations.

Participant B 00:35:56.260 – 00:35:56.860
Thank you very.

Miao, Yanwei 00:35:57.180 – 00:35:58.140

Thank you.

Bibliography

[1] Ameli, Nadia and Nicola Brandt. "Determinants of households' investment in energy efficiency and renewables: evidence from the OECD survey on household environmental behaviour and attitudes," *Environmental Research Letters*, *10*(4):044015 (apr 2015).

[2] Anderson, Allison. "Climate Change Education for Mitigation and Adaptation," *Journal of Education for Sustainable Development*, *6*(2):191–206 (2012).

[3] Bertram, Christoph, et al. "Energy system developments and investments in the decisive decade for the Paris Agreement goals," *Environmental Research Letters*, *16*(7):074020 (jun 2021).

[4] Brugger, Heike, et al. "Energy Efficiency Vision 2050: How will new societal trends influence future energy demand in the European countries?," *Energy Policy*, *152*:112216 (2021).

[5] Consentec, Fraunhofer ISI, Stiftung Umweltenergierecht. "Batteriespeicher in Netzen - Schlussbericht. im Auftrag des Bundesministerium für Wirtschaft und Energie (BMWi)," (33/18) (April 2021).

[6] Danish Energy Agency, "Technology Data." https://ens.dk/en/our-services/projections-and-models/technology-data, 2023.

[7] Energize Connecticut, "Home Energy Solutions." https://energizect.com/energy-evaluations/HES. Accessed: 2023-05-15.

[8] Energy saver, "Professional Home Energy Assessments." https://www.energy.gov/energysaver/professional-home-energy-assessments. Accessed: 2023-05-15.

[9] European Commission, "PHOTOVOLTAIC GEOGRAPHICAL INFORMATION SYSTEM." https://re.jrc.ec.europa.eu/pvg_tools/en/. Accessed: 2023-05-16.

[10] European Commission, "A Clean Planet for All. A European Long-Term Strategic Vision for a Prosperous, Modern, Competitive and Climate Neutral Economy," 2018.

[11] European Commission, "Climate change mitigation and adaptation," 2021.

[12] Eurostat, "Energy consumption in households." https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_consumption_in_households, 2023.

[13] Federal Office for Economic Affairs and Export Control, "Energy." https://www.bafa.de/EN/Energy/energy.html, 2023.

[14] Fernando, Martins, et al. "The Role of Electrification in the Decarbonization of the Energy Sector in Portugal," *Energies*, *15*(5) (2022).

[15] Fraunhofer ISI, "NewTRENDs: New trends in energy demand modeling," 2023.

[16] GERRING, JOHN. "What Is a Case Study and What Is It Good for?," *American Political Science Review*, *98*(2):341–354 (2004).

[17] Google, "Display live data on your site." https://developers.google.com/chart, 2023.

[18] Gunning, David and David Aha. "DARPA's Explainable Artificial Intelligence (XAI) Program," *AI Magazine*, *40*(2):44–58 (Jun. 2019).

[19] Highcharts, "Simply Visualize." urlhttps://www.highcharts.com, 2023.

[20] Hinz, Eberhard. "Kosten energierelevanter Bau- und Anlagenteile bei der energetischen Modernisierung von Altbauten," *Institut Wohnen und Unwelt* (2015).

[21] Hummel, M., et al. "The costs and potentials for heat savings in buildings: Refurbishment costs and heat saving cost curves for 6 countries in Europe," *Energy and Buildings*, *231*:110454 (2021).

[22] IEA, "The Critical Role of Buildings." https://www.iea.org/reports/the-critical-role-of-buildings, 2019.

[23] IEA, "Key World Energy Statistics," 2021. https://www.iea.org/reports/key-world-energy-statistics-2021.

[24] IPCC, "Climate change: a threat to human wellbeing and health of the planet. Taking action now can secure our future," 2022. https://www.ipcc.ch/2022/02/28/pr-wgii-ar6/.

[25] Kelly, Jack and William Knottenbelt. "The UK-DALE dataset, domestic appliance-level electricity demand and whole-house demand from five UK homes," *Scientific Data*, *2*(150007) (2015).

[26] Kim, Sunnie S. Y., et al., "Explainable AI for End-Users," Apr. 2023.

[27] Lacal Arantegui, Roberto and Arnulf Jäger-Waldau. "Photovoltaics and wind status in the European Union after the Paris Agreement," *Renewable and Sustainable Energy Reviews*, *81*:2460–2471 (2018).

[28] Langsdorf, Susanne. "EU Energy Policy: from the ECSC to the Energy Roadmap 2050," *Green European Foundation: Brussels, Belgium* (2011).

[29] Nicola, Armaroli and Balzani Vincenzo. "The Future of Energy Supply: Challenges and Opportunities," *Angewandte Chemie International Edition*, *46*(1-2):52–66 (2007).

[30] Nunes, Ingrid and Dietmar Jannach. "A Systematic Review and Taxonomy of Explanations in Decision Support and Recommender Systems," *arXiv*, (2) (Jun. 2020).

[31] Palmer, Karen, et al. "Assessing the energy-efficiency information gap: results from a survey of home energy auditors," *Energy Efficiency*, *6* (2013).

[32] Pecan Street Inc, "Better tech, better decisions, a better world we're making it happen.." https://www.pecanstreet.org/, 2023.

[33] Ruth, Matthias. *Handbook of Climate Change Mitigation and Adaptation* (2 Edition). Springer Nature, 2017. Foreword.

[34] Sauerwein, Elmar, et al. "The Kano Model: How to Delight Your Customers," *International Working Seminar on Production Economics*, *1* (01 1996).

[35] Siepmann, Clara and Mohamed Amine Chatti, "Trust and Transparency in Recommender Systems," Apr. 2023.

[36] Sioshansi, Fereidoon. *Consumers, Prosumers, Prosumagers: How Service Innovations will Disrupt the Utility Business Model*. Elsevier Inc., 2019.

[37] Swearingen, Kirsten and Rashmi R. Sinha. "Beyond Algorithms: An HCI Perspective on Recommender Systems.". 2001.

[38] Typeform, "Forms that break the norm." https://www.typeform.com/, 2023.

[39] UNFCC. "Paris Agreement.". 2015. https://unfccc.int/documents/184656.

[40] World Wildlife Fund, "What's the difference between climate change mitigation and adaptation?." https://www.worldwildlife.org/stories/what-s-the-difference-between-climate-change-mitigation-and-adaptation, 2023.

[41] Wulf, Volker, et al. "Engaging with practices: Design case studies as a research framework in CSCW.". 505–512. 03 2011.

[42] Yu, Songmin, et al., "Modeling of prosumagers and energy communities in energy demand models. (newTRENDs - Deliverable No. D5.2)," 2022. https://newtrends2020.eu/publications/.

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