# Design Visions for Future Energy Systems

*Towards Aligning Developers' Assumptions and Householders' Expectations*

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# Design Visions for Future Energy Systems: Towards Aligning Developers' Assumptions and Householders' Expectations

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We increasingly see smart energy technology moving into peoples' homes, designed to support householders in strategically managing different forms of energy conservation. Often, design visions for such technologies assume householders will accept smart energy systems as long as the interaction remains effortless, efficient, and convenient. Likewise, developers rely on assumptions that smart energy technologies meeting such usability goals may urge householders to become active players in a future energy market. Yet, a growing body of HCI research illustrates that actively engaging people with sustainability issues through technology requires more than merely meeting usability goals. Against this backdrop, our study investigates the design vision of a cutting-edge home energy management system created as part of an EU project and householders' expectations of it. Our findings highlight (mis)alignments that emerged from a questionnaire study with 167 households participating in a field trial of the developed technology. We use the insights to discuss the alignment of sustainable visions, HCI, and the design of future energy systems.

CCS Concepts: • **Human-centered computing → Empirical studies in HCI**.

Additional Key Words and Phrases: Sustainability, human-centred energy, domestic, smart energy technology, HEMS, energy flexibility, local energy systems

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## 1 INTRODUCTION

In Western societies, electricity is a resource readily available whenever people need it. One result of having stable and infinite access to electricity is that consumption becomes 'invisible', meaning most people give little or no attention to how electricity is produced, distributed or consumed when going about their everyday life [44]. The stability of this resource is in part a result of well-defined relationships in the energy sector between electricity producers, transmission- and grid-network operators, and people needing to consume this resource [19]. Yet, more and more electricity is produced from renewable resources (e.g. wind, water, and sun), and more and more energy demand is turning electric (e.g. electric vehicles for driving and electric heat pumps for heating) [8]. To overcome potential fluctuations in unpredictable production and consumer demand, we see digital technology emerging transforming the underlying infrastructure that aligns electricity demand to when and where renewable energy is being produced [5, 43, 61, 62].

In transition toward a renewable European future, the EU prioritises actions that "*make renewable energy technologies more easily accessible and affordable for EU citizens, so citizens also become more empowered*" [10]. To help realise this future, we see large-scale EU and national research projects [5, 17] exploring various possibilities for engaging the EU energy consumer with smart renewable energy. A shared vision in these projects is to design new digital infrastructures supporting interested actors to create untried energy markets that will "*make it easier for citizens to form energy communities and to produce, store and sell their own renewable energy*" [10].

A suggested vision to conceptualise a renewable energy future is 'flexibility" markets. Flexibility in this context is conceptualised as energy consumers' ability to be flexible as to where and when they consume electricity. Since all consumers are connected to the same electricity grid(s), this flexibility can be commodified, traded and sold [43]. In these future energy markets, interested actors are envisioned to form virtual or physical micro-grids [62], where a suite of smart energy technology enables actors to control, own, and optimise local renewable electricity [61]. However, these energy markets rely on householders' willingness to trade their flexibility and shift electricity demand in time or place [45, 47]. To support householders' engagement in these markets, the EU envisions this will "*require a high level of digitalisation and automated communication and control in ways that will benefit consumers, as they can get better control over their energy consumption*" [9].

When acting in domestic environments, these digitalised energy systems are commonly referred to as Home Energy Management Systems (HEMS). The design of HEMS is currently explored in various "technology-centred" research projects [5] speculating that technologies alone will foster household engagement, as long as the householders having to live with them only experience minor inconveniences and discomforts in their everyday life [14]. In these technology-centred projects, new energy solutions are predominantly designed "top-down" [33], meaning the focus is overwhelmingly on framing technical needs assembled by actors in the energy sector [17]. As a result, the attitudes, expectations, and energy-consuming practices of the end-user are only marginally integrated into the design of these technologies [5].

This technology-centred focus is likewise apparent in the EU's vision of future energy systems and how the EU envision householders will engage in these new renewable technologies [8–10]. Embedded in EU's vision is underlying assumptions that EU householders will welcome smart and ***automated*** renewable energy technologies as empowering ***digitalised information*** tools to support their individual needs of ***accessing*** the renewable energy market [9]. Nonetheless, householders having to embed these technologies in their everyday life are rarely involved in the design process of future energy systems [17, 33, 54]. Thus, we often see misalignments between what people experience and expect of smart energy technologies and the visions developers inscribe into the design of these technologies [17, 30, 32, 55, 56, 64].

In this paper, we bring forth a human-centred perspective to investigate the design vision of a cutting-edge energy flexibility system created as part of an EU project. The project's overall aim was to develop a variety of HEMS allowing interested actors to trade flexibility on a local, renewable energy market at three different demonstration sites across Europe. This study aims to understand potential (mis)alignments between the project's design assumptions and householders' expectations and experiences of living with the technology.

The paper offers three main contributions. First, we analytically identify three design assumptions embedded in the vision of the project. Second, we invited 167 households participating in the project to evaluate their experiences and expectations of living with the developed technology via a questionnaire. Third, we use these insights to discuss points of convergence and divergence between the developers' assumptions and householders' experiences and expectations of future energy technology as a departure for future design activities.

## 2 RELATED WORK

To better align electricity demand with renewable production, we see assembles of new energy infrastructures where energy flexibility is a commodity that can be traded [61]. In the following, we depict two different human-centred perspectives on designing interactions encouraging householders to engage with future energy systems.

### 2.1 Individual-based Design

Designing human-centred interactions seeking to encourage individual householders to align their energy consumption with renewable energy production is an interaction design strategy known as ***shifting*** [45, 47]. In the sustainable human-computer interaction (HCI) research community, shifting is increasingly being investigated as a design strategy [7, 31, 34–36, 52]. This body of work is predominately focusing on how design may encourage change in individual user behaviours by raising awareness through eco-feedback [16, 39], or support sustainable change through intelligent and automated technology designed to introduce only minor inconveniences in a busy everyday life [29, 51].

However, embedded in those design visions is the assumption that individual householders are interested and willing to trade flexibility. While it is technically possible to capture, represent, and model energy flexibility as a commodity that can be traded in a smart energy system, [14, 40, 43], human-centred studies show that engaging households in this different and more active role of conserving electricity are impractical to act upon [29, 47, 57, 58].

For instance, Rasmussen et al. [49] studied an eco-feedback design for shifting and found that while the design increased participants' awareness, some also reported newfound guilt when they did not manage to align their energy demand with system recommendations. Pierce and Paulos discuss that shifting requires altering everyday practices and some of these are highly resistant to change [46]. Likewise, Svangren et al. [59]'s study can be challenging in a busy everyday life.

Other studies show how automated technology may support householders to shift energy embedded in domestic practices. Bourgeois et al. [2] and Costanza et al. [12] studied how automated technologies can be designed to assist with shifting washing activities. Both studies highlight that automation plays a pivotal role in controlling the right time to wash. Alan et al. [1]'s different prototypes simulate dynamic energy pricing as an incentive to engage households to shift consumption. Together the studies demonstrate alternatives to automating some of the more tedious decision-making in shifting. Yet, studies illustrate a design predicament of technology that quietly operates in the background and meddling technology aiming to foster proactive household engagement [28, 29].

Furthermore, research shows that householders' values and expectations of smart energy technologies shape consumption in ways that may be misaligned with the sustainable vision of the designers, developers, and other actors from the energy sectors [15, 20, 22, 24, 30, 33, 60, 64]. Tuomela et al. [60] study of smart home energy management systems (SHEMS) illustrates that users' values such as stimulation, creativity, and autonomy conflict with designers' assumptions that users are primarily motivated by economic gains and environmental concerns. Nyborg and Røpke [42]'s study of smart energy technology highlights that the vision of the smart home is a fusion of different technologies that influence sustainable consumption differently. Likewise, Wilson et al. [64] argue that prospective users and industry developers do not consistently share visions of the sustainable smart home. Lastly, Strengers et al. [55] points out that designers embed desires into the visions of these technologies that may end up intensifying electricity consumption rather than support householders to act more sustainably.

### 2.2 Community-based Design

Despite smart home technology design being partly envisioned to shape electricity consumption within individual households, the domestication of these also fosters new possibilities for transforming the energy system towards a more interactive, transparent, democratic and collaborative system [5, 6, 27, 33, 63]. An assumption that householders will actively participate in trading electricity and flexibility on (local) smart energy markets underpins this vision. In the EU, future renewable energy systems are commonly conceptualised as energy communities [9, 10, 61].

However, trading energy as part of an energy community has only sparsely been studied from a human-centred perspective. Wilkins et al. [63] explore how future digital infrastructures may create peer-to-peer energy markets to support people to participate in buying, selling, and billing energy. The authors highlight that design principles related to privacy, security and data governance are pivotal for prospective householders' willingness to engage with trading energy in everyday life. Jabbar and Bjørn [27] unfold blockchain technology as an information infrastructure attempting to transform existing markets like future energy communities. The authors emphasise that such new infrastructures are evolving socio-technical relationships that iteratively reconfigure domestic practices, shaping how people use energy.

Exploring how householders may experience community-based eco-feedback, Hansen et al. [21] developed 'Lumen', a design that supports householders to gather in virtual energy communities. Likewise, Jensen et al. [32] study how families experience having to collaborate as virtual groups in shifting energy. Both studies highlight that group pressure and competitiveness may foster experiences of guilt and disengagement unintended by the developers and designers. Simm et al. [52] studied a small community located on a remote island that heavily relies on electricity produced from a community-owned wind turbine. The authors found that social engagement in the community influenced energy-consuming habits without the financial incentive to do so. Dillahunt and Mankoff [13] studied a community-focused monitoring app for energy conservation to explore how group dynamics may impact energy consumption. They found that context knowledge of community members, accountability and normative consensus are key points in community-based applications.

Furthermore, Huang et al. [26] argue that designing complex digital infrastructures like future smart energy systems requires a socio-technical approach to account for both the social complexity and the development of large-scale digital technology. Similarly, Hasselqvist et al. [23] explored how to design amateur energy advice for apartment buildings owned by housing cooperatives and found that sharing such advice motivates users and enables learning. The common narrative in these studies is that how householders engage with energy communities depends largely on the local context and how developers and designers approach the design of technologies.

## 3 THE GOFLEX PROJECT

The research presented here is part of a larger H2020 EU project named the GOFLEX project [11, 18, 41]. The project ran for three years and four months. Amongst others, a suite of HEMS technologies was developed during the project with a vision to engage households to trade energy flexibility locally.

Similar to other EU projects [17] aiming to develop future renewable energy systems, the GOFLEX project comprised multiple partners from across Europe that were associated with the energy sector. Project partners included hardware and software companies working with energy technology, utility and energy companies, grid-network operators, and leading research institutions within the energy and computer sciences. The GOFLEX project overall mission was stated

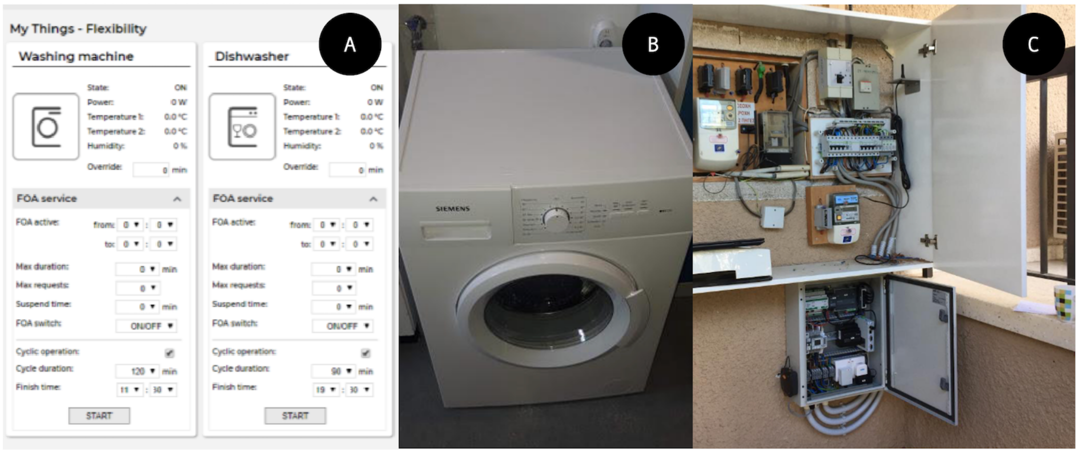


Fig. 1. GOFLEX project household HEMS technology: A) An English version of a user interface to control flexibility parameters from the Cyprus demonstration site. B) A washing machine controlled by a smart plug at the German demonstration site. C) HEMS technology installed next to the meter cabinet in a household in Cyprus.

as follows; *"the GOFLEX partners aim to create an integrated set of hardware and software technologies, which provide attractive solutions for actors who want to use smartly, provide or trade flexibility through the distribution of renewable energies on a regional level"* [18].

Because of the nature of EU-funded projects, (e.g., required deliverables, the production of scientific knowledge) – sound (and agile) software engineering in such research projects are often un-mirrored in the project management [50]. As a result, the software development methods in these project typically do not reflect the values and active participation of the end-user communities [33, 50], but instead resemble more traditional software development approaches that focuses on comprehensive documentation and following a plan [3]. This more traditional software development approach were evident in the management of the GOFLEX project. This meant that a coherent set of functional requirements – stated in project deliverables [11, 18] – was established at the beginning of the project, primarily informed by business cases derived from partners within the project with a strong focus on the technical qualities of the system [41].

As a result, the GOFLEX technology was inherently created from a technology-centred perspective [5, 32], where the partners were naturally interested in designing and constructing innovative and complex technological solutions. The partners approached the development of these new energy solutions "top-down" [33], which meant that the project's focus was mainly on constructing technical solutions from needs and requirements assembled by project partners [11, 41]. Authors 3 and 4 participated in the development of these software solutions.

This also meant, that the people intended to interact and use the system had minimum involvement in developing the requirements, although the system was mainly designed for them and required their active participation. Thus, the developed HEMS technologies were envisioned without the active participation of private householders. This approach to design can also be viewed as a techno-solutionist perspective [5, 32, 33], where design is driven by the belief that technological constructions in their own rights can solve complex societal challenges, such as sustainable change. A small HCI team became involved at the end of the project to help evaluate household experiences with the developed HEMS technologies. Author 1 actively participated in project meetings to obtain an understanding of the project's goals and developed technology before staging the evaluation activities.

At the point of the HCI team's involvement, the project partners had almost finalised the development of the HEMS technology targeted households. Two HEMS were developed very similar at their core (both provided the necessary technological infrastructure to commodify energy flexibility traded in a local renewable energy market) but different in the types of devices that could be controlled. The two HEMS (see Fig. 1) were deployed in three demonstration sites across Switzerland, Cyprus, and Germany.

Each demonstration site was located in small rural towns that had invested extensively in renewable production technologies. At each demonstration site, three local utility companies – and partners in the GOFLEX project – were responsible for; 1) recruiting households from their pool of energy customers to help demonstrate the developed GOFLEX technology and 2) installing and updating the hardware and software components in participating households.

Over 350 households participated in the HEMS demonstration trial of the system. The households were recruited to be part on the GOFLEX demonstration with incentives such as; 1) being promised the capability to monitor consumption and production of household energy, 2) being able to participate in the energy transition, and 3) make better use of local renewables [18]. By the time the project ended, the technology had been operated in these households for two to five months. See [41] for more details on developed GOFLEX technology operating at the three demonstration sites.

In **Switzerland**, the HEMS automatically controlled electrical heating devices (electric heat pumps and/or boilers) used for domestic hot water heating. The HEMS collected information about real-time indoor measurements to be able to uphold comfort constraints. Households controlled flexibility parameters by interacting with their heating system. They also had access to a website containing historical information about their overall electricity consumption, heat pump/boiler consumption, water temperature, measured indoor temperatures, and green energy advice.

In **Cyprus**, the HEMS controlled household appliances via smart plugs (e.g. A/C's, fridges, washing machines, and dishwashers). The appliances controlled by the HEMS were chosen by the utility company that came to install the system. In this HEMS instantiation, participants were able to control flexibility parameters directly via a web app (see Fig. 1-A and C).

In **Germany**, both HEMS were deployed. About half trialled a similar HEMS like the one in Switzerland and the remaining half like the one in Cyprus. Contrary to the Cyprus demonstration site, participants decided which appliances they wanted to be controlled by the HEMS (see Fig. 1-B).

## 4 STUDY DESIGN

One of our motivations during our project participation was to identify potential (mis)alignments between GOFLEX project developers' assumptions about human engagement and householders' expectations. The following two sections outline how we conceptualised and devised; 1) three overall design assumptions of the GOFLEX project via a content analysis and 2) householders' experiences and expectations of GOFLEX project technology via a survey study.

### 4.1 Developers' Design Assumptions

As a first step, we set out to conceptualise the design assumptions embedded in the vision of the GOFLEX project. For this, we performed a content analysis [38] on the publicly available project information in the form of project deliverables, news segments, and public descriptions of the project [11, 18].

The content analysis was conducted as follows. First, we familiarised ourselves with the content by reading the publicly available project information that specified user and system requirements. We focused on the partners' envisionments of household engagement during this read, both in the establishment of the HEMS requirements and how partners conceptualised the interaction with the two HEMS in a domestic space. Second, we conducted the content analysis via a priori coding approach [38]. During the priori coding process, we identified three potential categories (flexibility market dynamics, automation and digitalisation) underpinning both relevant framings reported in related work [1, 53, 54, 63], and the EU's vision for future flexibility markets energy in the union [9] (as quoted in the introduction).

We used this as an analytic device to develop an understanding of how GOFLEX project partners and developers inscribed householders' assumed intent into the developed HEMS technology as stated by their own description of requirements and system specifications. The results of our analysis are structured into three overall design assumptions. We summarise these as follows;

***Design Assumption 1: Access to a local, renewable energy market,*** will empower householders to sell, buy and store locally produced renewable energy. The existence alone of a local renewable energy market will ensure a *"transformative market liberalisation"* as energy flexibility now can be commodified. Householders engage with this market by trading their energy flexibilities of specific domestic devices to *maximise gains in a socio-economically fair and effective way*. For example, the energy flexibility of a washing machine in a single household can be determined based on the best running time for this specific device. The value of energy flexibility, in this case, is then determined by the households' willingness to run their washing machine at a time when local, renewable energy is produced. Thus the socio-economically gain for the individual household depends on the inconveniences and discomforts the household may want to encounter, as they may have to change the time when they need to consume energy. As a result, dynamic pricing of energy flexibilities and the idea of supporting the local, renewable energy system will engage householders to interact with their HEMS.

***Design Assumption 2: Digitalisation of energy information,*** will ensure householders become aware of the existence of the local renewable energy market. Further, digitalised information about individual households' energy needs and preferences will also ensure the HEMS can intelligently provide the best strategy for managing energy flexibilities to serve interested actors. As the HEMS can provide *various digitalised energy information*, this information fosters *engagement and empowerment for householders to participate actively* in the energy market. The digitalised information may include historical and near real-time energy data, the price of energy and energy flexibility, what and when the household consumes energy, environmental data, and their own energy production (if applicable). The digitalised energy information also allows householders to control (directly or indirectly through other systems) different preferences of their energy flexibility according to their own individual needs and comfort settings. Thus, having this information will empower householders to stay managed regarding their energy consumption and ensure their comfort needs are met.

***Design Assumption 3: Automated household technology,*** will ensure that householders engage with the local renewable energy market with minimal interactive effort while the system respects individual household constraints (e.g., on comfort). The *right mix* between automation and user input will be beneficial for the householder. Thus, user satisfaction with the home energy management system is achieved by automating the energy consumption of various devices. As the HEMS is responsible for this, householders will *appreciate* that the system requires minimal interaction. Simultaneously, HEMS' built-in learning algorithms will *foster engagement* by taking into consideration each household's energy strategies and behaviours, local production and consumption parameters, and local environmental parameters.

### 4.2 Householders' Expectations

To obtain insights into householders' expectations and potential (mis)alignments with the three design assumptions, we chose to conduct a survey study with households participating in the demonstration of the GOFLEX technology. For this, we developed a survey instrument. We decided on this research approach as it is particularly suitable for measuring "*attitudes, awareness, intent, and user experience responses from a large number of people within a well-established target group*" [38]. In our case, the target group was composed of domestic energy clients recruited across the three demonstration sites by the utility companies participating in the project. Furthermore, a survey instrument allowed us to have more breadth in our understanding of how GOFLEX project technology was experienced by the households at the three demonstration sites.

We designed the survey with both closed- and open-ended questions. The open-ended questions were designed to provide qualitative insights into participants' experiences [38]. The closed-ended questions were designed to be assessed on a 5-point Likert scale [38] (from 1=strongly disagree to 5=strongly agree) with an additional "I don't know" response option. An "other - please specify" response option was also added to all survey items. Some survey questions were adapted and refined from Wilson et al. [64]'s survey study on prospective users' perception of smart home technologies. We designed the closed- and open-ended questions to cover *the past* – what motivated households to participate in the GOFLEX project –, *the present* – current experiences of using the GOFLEX technology –, and *the future* – expectations of use and risks of GOFLEX technology.

We structured the survey in two parts. Part A comprised demographic questions related to the respondent's age, gender, housing situation, motivation for participating in the project, and tailored questions to the three specific demonstration sites. In Part B, we designed questions unfolding and assessing the overall household experiences and expectations of GOFLEX technology use across the three demonstration sites. Part B was designed with both open-ended and close-ended questions.

The open-ended questions asked respondents to 1) describe with three words the *"first things that come into your mind when you think about GOFLEX technology"*, 2) express their understanding of the positive and negative aspects GOFLEX technology, and 3) their input into future use, risks and functionality. The first close-ended questions of Part B contained questions as to why and what motivated them to participate in the GOFLEX project (past). The following two consisted of detailed questions assessing the respondents' experiences and expectations of their current use of GOFLEX technology (present). The last two were devised to assess expectations for future use of GOFLEX technology (future). These close-ended questions were designed and ordered as follows;

- The *motivation* for participating in the GOFLEX project (4 questions).
- The *purposes* of GOFLEX technology (5 questions).
- The *design* of GOFLEX technology (6 questions).
- The *future use* and *expectations* of GOFLEX technology (6 questions).
- The *future risks* associated with GOFLEX technology use (6 questions).

Furthermore, we developed additional questions targeting respondents' differences in experiencing the multiple versions of the HEMS technology across the three demonstration sites. Those results have been reported elsewhere [18, 41]. In this paper, we unfold the overall household experiences and expectations across the three demonstration sites and their relation to the GOFLEX design vision as we focus on potential (mis)alignments between the developers' design assumptions and householders' expectations. Towards this, the open-ended questions expand these insights with diverse accounts of how participants experienced the GOFLEX technology. The survey was hosted on SurveyMonkey and translated into the language of the three demonstration sites; French for Switzerland, German for Germany, and Greek and English for the Cypriot demonstration site. The partnered utility companies distributed the survey to households participating in the GOFLEX demonstration of the HEMS.

The survey was sent out to a total of 304 participating households, and 167 provided anonymous responses. In Switzerland, the survey was sent out to 180 participating households with 102 responses. In Germany, the survey was sent out to 106 participating households with 52 respondents, while in Cyprus, the survey reached 18 with 13 respondents. The data collection period lasted four weeks and took place in January and February 2020. At this point, the participating households had experienced the GOFLEX technology between two to five months.

## 5 FINDINGS

Overall, the respondents were inherently interested in engaging with the survey. Of the 167 responses, 144 respondents also answered the open-ended questions. In terms of demographics, most respondents were in the age range of 35-44 (31%) and 45-55 (28%), while 13% belonged to the 25-34 age group. 79% of the respondents self-identified as male, 20% as female, and two (1%) preferred not to disclose their gender. The vast majority of participants lived in a house they owned (82%), while the remaining either owned apartments (6%), rented (11%) or had other housing arrangements (5 respondents). Two participants chose not to disclose any information concerning their housing. A majority of participants lived in 4-member families (35%) or 2-member families (27%). The characteristic of this demographic reflects other studies [53, 64] reporting on householders who have an inherent interest in smart (energy) technology. Fig. 2 summarises the respondents demographics.

The following subsections present the results of the univariate analysis [38] we performed in the collected data. For the close-ended question we report on the calculated percentage of the response for each of the options. For the five main questions assessed on the 5-point Likert scale, we also report on the calculated weighted average (omitting the "I don't know" answers ) by weighing the scales from: 1=strongly disagree to 5=strongly agree.

We structure the findings after how we designed the five main close-ended questions namely; 1) household motivation (past), 2) energy information and automated control (present), and 3) future use, expectations and risks (future). We supplement these findings with responses from the open-ended questions – quoted verbatim.

### 5.1 Householders' Motivation

In the survey, we asked the respondents what motivated them to participate in the GOFLEX project (see Fig. 3). The respondents were asked to rate each of the statements in terms of importance. Responses from the four response options

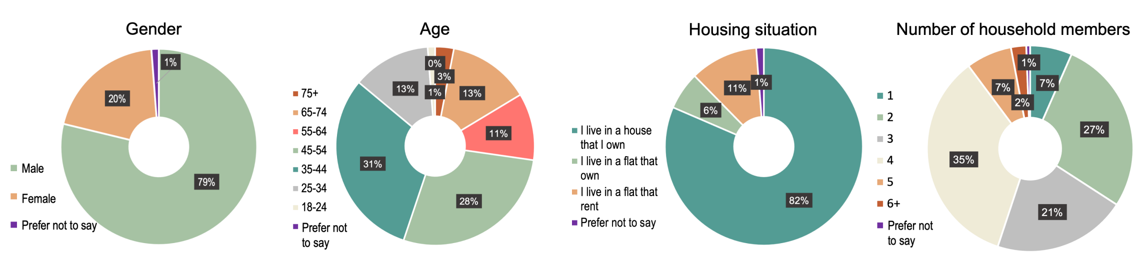


Fig. 2. Demographics of the respondents.

clearly state that the highest-ranked motivational factor for participating in the GOFLEX project was "*wanting to try out new technology*" with 74% respondents strongly agreed or agreed (Weighted Average=4.2), closely followed by "*doing something good for the environment*" (WA=4.1). "*Doing something good for the local community*" was ranked important but also the lowest ranked factor with 47% respondents strongly agreeing or agreeing (WA=3.6). Lastly, "*saving money on energy*" was the third-ranked motivational factor with 64% respondents strongly agreeing or agreeing (WA=3.9).

The open-ended questions helped clarify why households ranked the motivational factors to participate in the GOFLEX project and engage with the local energy flexibility market this way. When asked about the positive and negative aspects of the technology, most respondents gave supplementary insights (also reflected in the word-cloud visualisation describing the GOFLEX project at the Swiss demonstration site - see Fig. 4). Some respondents stated that one of the positive things about participation was getting "*acquainted with new technologies*" (German Respondent - GR). Others stated that the technology was "*innovative, particular with the smart plug*" (Cypriot Respondent - CR) and just some "*very interesting technology*". Thus, rather than doing something good for the local community or saving money, the respondents stated they were mainly motivated to participate in the GOFLEX project because they found the technology fun and innovative to experiment with, contrasting the project's design assumptions. Other research [30, 60, 64] supports these findings as indications show that householders bring these technologies into the home due to other desires (e.g., playful, fun), which are not explicitly related to their actual function or purpose to optimise energy consumption.

However, some respondents also expressed difficulties engaging with the overall project vision in the open-ended questions. One expressed this as; "*a team came to install the system but unfortunately we did not have precise explanations on GOFLEX project - it's a shame..!*" (Swiss Respondent - SR). Another stated that a "*lack of details on this technology, - ultimately we do not really know what it is for*" (GR). Moreover, while some expressed an understanding of the overall vision of trading their energy flexibility, lacking information made them self-doubt this; "*I lack information on the functioning and the ultimate goal of GOFLEX project . I thought that with GOFLEX hot water would be produced when my solar panels produce electricity, which will save me costs?*" (SR). Others expressed a concern that other members of the household would not be able to understand GOFLEX technology the same way; "*How am I going to explain this to my wife?*" (SR). Together, these findings indicate that designers of these technologies have to embed the vision in the

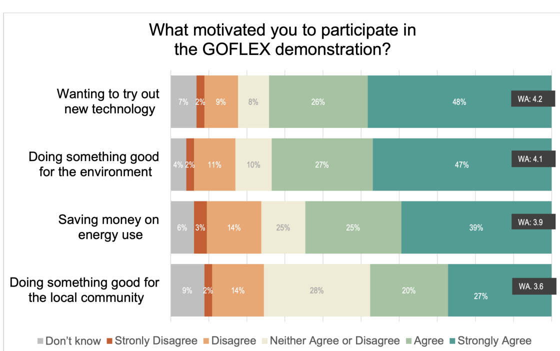


Fig. 3. Ranked motivational factors for participating in the GOFLEX project.

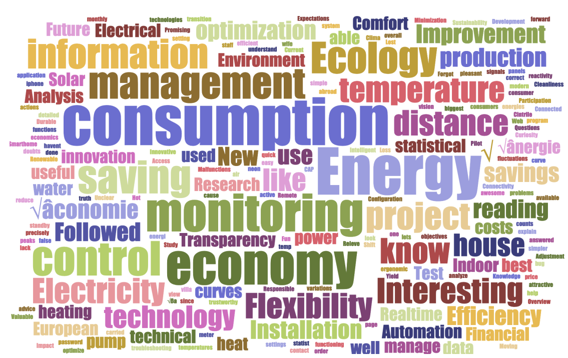


Fig. 4. Words used to describe GOFLEX technology at the Swiss demonstration site (based on 80 responses) presented in a word-cloud visualisation.

technology better and provide more detailed information about the objectives so people having to live with technologies are not left doubting their function and purpose.

### 5.2 Energy Information & Automated Control

We also asked the respondents about their understanding of the overall purposes of the GOFLEX technology (see Fig. 5). From the response, we observe that 71% of the users agreed or strongly agreed that the main purpose of the technology was to provide information about their energy use (WA= 4.0), correlating well with design assumption 2. This was followed by "*help me to use* less *energy*" (WA=3.7). Interestingly, "*help me to use clean energy*" was ranked the lowest of the suggested purposes of the technology with 33% respondents strongly agreed or agreed (WA=3.2), while "*help me control my home appliances*" was ranked the third lowest (WA=3.4). As the prominent vision of the GOFLEX project is to exploit local renewable energy, the purpose of the technology is not to use *less* energy but rather to align consumption needs with the production of local, renewable, and clean energy. This vision of clean energy is also reflected in all three design assumptions, particular design assumption 1. Thus, as this response indicates – respondents encountered difficulties understanding the overall flexibility purpose of GOFLEX technology even after experiencing living with the GOFLEX technology for a period of time.

An additional survey question probed the respondents to reflect upon their understandings of what GOFLEX technology is designed to do. The response further illustrates that these technologies are dominantly seen from an energy information management perspective (see Fig. 6). 69% of the respondents agreed or strongly agreed that GOFLEX technology was designed to "*provide more information about my energy use*" (WA=4.1), aligning adequately with design assumption 2 of the GOFLEX project. However, more respondents (WA=3.8) understood the technology was designed to "*enable my household to manage energy use*", rather than "*manage energy use on behalf of my household*" (WA=3.6). This response underpins the complexity of aligning visions embedded in design assumptions 2 (empowerment through energy information) and 3 (appreciation of automated energy control) of the GOFLEX project. Ultimately, the participants seemed somewhat confused about the balance of automated system control and human control. A point also illustrated by 30% who answered that they did not know how to rank if the system "*operated only when activated*".

The open-ended questions provided more insights into the householders' expectations of the home energy management system. The perplexity of why domestic devices were being controlled and by whom was also visible in these

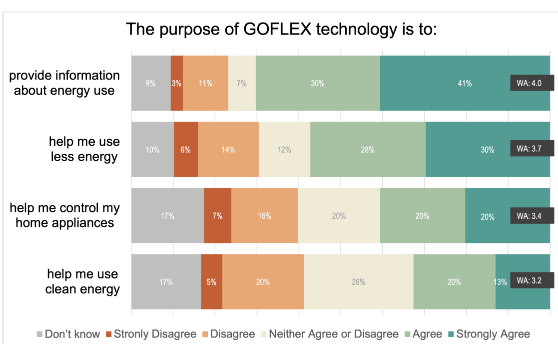


Fig. 5. Ranked purposes of GOFLEX technology.

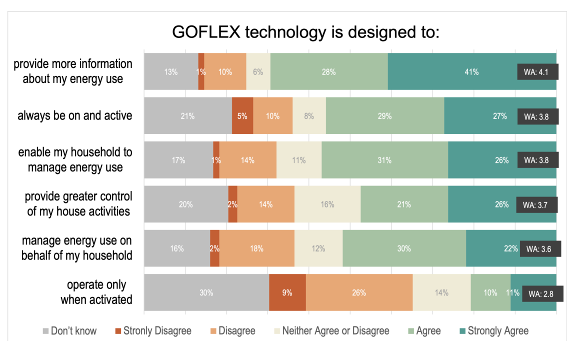


Fig. 6. Ranked design intent of GOFLEX technology.

answers. One stated that they liked the "*control and a sense of control*" (SR), while another found it comforting to "*have my household under control - especially when I'm away*" (GR).

The particular aspect of managing energy consumption by providing energy information seemed to be highly appreciated by many of the respondents as they were also the common words used to describe the GOFLEX technology (see Fig. 4). Many stated that it was promising to able to; "*see what devices use a lot of electricity*" (SR), "*have visibility on my consumption*" (SR), and "*reading the consumption values is a nice thing, and just like being able to switch off the sockets remotely*" (GR), "*know what we consume*" (SR), with a "*simple and efficient vision of energy consumption*" (GR).

Many also expressed that access to energy information gave them an alternative way to manage and "*monitor to understand consumption better*" (SR), as it allowed them to; "*interpret results and understand surplus or energy savings*" (SR), through these "*data visualisation in real time*" (SR). This gave a sense of being able to "*make evaluations of the energy consumption of individual devices*" (GR), that "*makes us aware of fluctuations in consumption and allows us to determine the sources*" (SR). Nevertheless, others stated that "*reading data is too complicated*" (SR) and that the interaction with the HEMS would be a better experience with the "*creation of a more joyful and user-friendly website*" (SR).

Others saw shifting (flexibility) in their energy data, which provided; "*awareness of energy consumption according to time slots allowed me to follow the statistics of my house (heating, water,....)*" (SR), that lead to an "*improved temperature monitoring and management)*" (SR) of the indoor climate. Moreover, householders that also produced energy saw an "*improved understanding on self-consumption for customers with PV production*" (SR). Some participants experiencing the HEMS controlling devices through smart plugs had slightly different experiences of GOFLEX technology shifting their consumption. One expressed that there "*were unnecessary cooling times*" (GR), and devices like the "*washing machine and dishwasher had to be switched on again by hand*" (GR). A respondent also felt that living the GOFLEX technology was "*high effort for (currently) absolutely zero benefits*" (GR).

### 5.3 Future Use, Expectations and Risks

Based on experiences of living with GOFLEX technology, we also asked participants about their future use and expectations (Fig. 7). 85% respondents agreed or strongly agreed that technology should be "*reliable to use*" (WA=4.5). The response to this question also highlights that 77% of the participants strongly agreed or agreed that "*security*" and 75% "*privacy, and confidentiality*" of higher importance than the system capabilities to "*manage energy use effortlessly and conveniently*" (WA=4.2) and "*automate my energy usage*" (WA=3.9), although being towering features of GOFLEX's design assumptions, particular 1 and 3. In fact, just around half (57%) of respondents agreed or strongly agreed with this form of automation and adhering to user constraints in the system to be of importance. This response highlights a misalignment between the GOFLEX design assumptions and what these participants expected.

An additional survey question probed the respondents to reflect upon their understandings of the risks the participants associated with the continued use of GOFLEX technology (Fig. 8). There seemed to be an agreement that there is a low risk that continued use would "*increase my dependence on technology*" as 28% of the respondents strongly agreed or agreed with this. Respondents also weakly stated (26% respondents strongly agreed or agreed) that use "*will increase my dependence on electricity networks*". Respondents saw that there was a lesser risk than GOFLEX technology would "*will invade my privacy and will result in loss of control*" (WA=2.5, and WA=2.7), aligning adequately with the vision of design assumption 1 of the GOFLEX project.

Intriguingly, the least associated risks were "*will disrupt my daily tasks*" (WA=2.5), and "*will decrease my comfort*" (WA=2.4). The participants of this study associated these risks to be of lesser concern than prospect smart home users in Wilson et al. [64]' study. The reason for this might be 1) an indication that many respondents in this study had a high interest in new and innovative technology (see Fig. 3), and 2) they associated GOFLEX technology as being rather trustworthy after already having experienced living with GOFLEX technology over a period of time. Nevertheless, these expectations align well with what the developers of the GOFLEX embedded in their design of the HEMS technology.

The open-ended questions provide more insights into how the participants understood these risks. Some respondents stated that because the GOFLEX technology was installed by the local utility company created insurance of the responsibility of technology. One stated that it was positive to have "*remote control from outside* " (GR), while another found it reassuring that more people kept an eye on the automated control; "*my heat pump broke down, we had to switch on the emergency electric heating on the heat pump, but we had forgotten to turn it off once the failure recurred. The GOFLEX project employees who noticed a high consumption came to check and notified us and we stopped it*" (SR). Having a "human" third party to help keep an eye has also been found to be a valuable feature in other studies [29, 60]. Moreover, having this human relationship with the utility company seemed to influence why some saw living the GOFLEX technology as a joyful experience; "*the guys who came to install it were nice*" (SR), while another found it convenient not having to install the technology themselves; "*it works correctly for monitoring electricity consumption, without having to implement the necessary technologies myself* " (SR).

However, not all had this joyful technology experience and highlighted potential risks associated with continued use. Some participants stated that technology was difficult to understand and therefore only "*being available for technicians (but it is a small evil to improve the future)*" (SR), "*it's not negative but I would need professional advice to help me adjust consumption)*" (SR). Others highlighted that they needed new skills and competencies to be able to understand and interact with the technology; "*I lack training)*" (SR), and "*lack of more information - advice, malfunction of devices, do not know if my house is piloted, what are the risks of this piloting, what is the flexibility of my house?*" (SR). Some also felt frustrated not being given the "right" information on the objective of the GOFLEX project; "*indirectly a slightly disappointed of not having received enough information from the GOFLEX system in order to be able to optimise and reduce our energy consumption costs)*" (SR). Others expressed concerns about being reliant on other technology to operate their GOFLEX HEMS fully; "*requires a continuous WIFI connection*" (CR), and "*without a super-fast connection, consulting information is really difficult*" (SR).

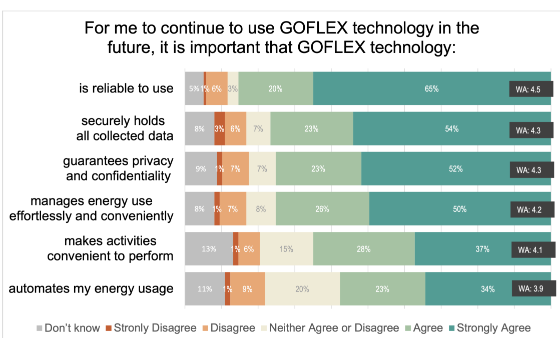


Fig. 7. Ranked expectations of future GOFLEX use.

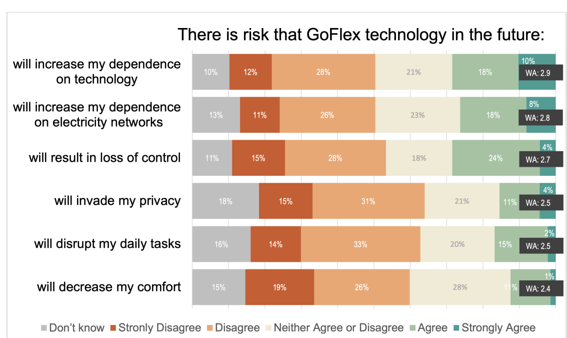


Fig. 8. Ranked risks of future GOFLEX use.

| Design Assumptions | Converging with household expectations | Diverging with household expectations |
|---|---|---|
| **1.** Access to a local, renewable energy market,.. | • Cutting-edge energy technology can facilitate trading of energy flexibility in an autonomous way without much disturbance in householders' everyday lives. | • Trading energy flexibility requires different user behaviour strategies that can be difficult for householders to grasp and engage in. |
| **2.** Digitalisation of energy information,... | • Home energy management and energy information can create engagement and energy awareness. | • It can be unclear where responsibility lays between system automation and user control. |
| **3.** Automated household technology,... | • New and innovative technology can foster experiential engagement and playful, fun experiences. | • Automation requires new skills and competences to enable householders to engage with technology. |

Table 1. Key implications: Points of diverging and converging alignments between the design assumptions embedded in HEMS technology and householders' expectations reflecting on living with HEMS

## 6 DISCUSSION

Our findings illustrate that identifying and articulating developers' design assumptions can provide an analytic device to help locate potential alignments and misalignments between visions of future energy systems and householders' expectations. Further, our findings highlight householders' expectations with future energy technology as everyday experiences sometimes complement and contradict the vision embedded in the materialised technology.

Below we synthesise our findings as key implications as points of diverging and converging alignments between design assumptions as understood by an EU-funded project, its partners and developers – and the experiences and expectations as reflected by householders living with the developed HEMS technology in real-life conditions. We summarise key implications in Table 1. We discuss in detail the implications of these findings for researchers and practitioners in the following towards aligning design visions of future energy systems and the people having to embed these technologies in everyday life.

### 6.1 Top-down Development vs Bottom-up Household Engagement

The conceptualisation of energy communities is part of the EU's vision to engage citizens in a future renewable energy system and combat escalating environmental problems [9, 10]. As depicted in this study, large-scale EU and national projects can now showcase and exploit various technological opportunities for everyday people to engage in such a vision [5, 15, 17, 33]. Despite more and more technology being designed and developed with the potential to radically transform how householders interact and participate in future energy systems [14, 43, 61], little research is conducted together with the people having to embed these future technologies in their everyday lives [5, 33]. Instead, effort in these projects is typically put into developing efficient and "correct" smart energy solutions, where the goal in itself becomes the construction of technology [33].

This technology-driven approach [5] was also used to develop the technology in the GOFLEX project. In this project, it was assumed that households would participate in flexibility trading as long as the technology would 1) provide

***access*** to the market, 2) digitalise energy ***information*** in a meaningful way, and 3) ***automate*** tedious shifting tasks with minimal interaction efforts required while ensuring minor potential inconveniences and uncomfortable disruptions when experiencing the smart energy technology in everyday life.

However, when participants were asked about expectations of automation and comfort, they did not rank these features as the highest priority. In fact, our findings illustrate that balancing between automation and human control when designing interactions for home energy systems is difficult to achieve. Many respondents of our study indicated they were not able to distinguish between GOFLEX technology controlling their energy use on their behalf or GOFLEX technology supporting them in controlling their energy consumption. Additionally, our findings imply that it was unclear to participating householders how sustainable energy efforts were achieved through the system. As also discussed by others [15, 22, 29, 53, 55, 60, 64] these misalignments often come about because the social aspects of domestic energy-consuming practises are often uncounted for when envisioning and designing smart future energy technologies.

Moreover, our findings indicate that it was not clear for many participants what the overall purpose of GOFLEX technology was concerning using renewable energy. Instead, the survey responses imply that the respondents' expectations of the HEMS resemble more common ideas and expectations of renewable energy systems. Namely, make it possible for an individual household to manage energy use through information to **reduce** energy [64]. In contrast (e.g., keeping a comfortable household temperature), textbfshifting as an energy strategy may, in some cases, lead to actually increased energy use as long as the energy is produced from renewable sources [29, 43]. Our findings illustrate that understanding shifting as a renewable energy strategy can be complex for householders to apprehend as practical knowledge. Other studies highlight [29, 45, 47, 49] that shifting is challenging to design for as it requires households to change routinised and familiar use patterns.

Therefore, we believe this to be an important call for designers, HCI researchers and developers to engage in the analysis, design, and critique of the construction of future energy systems envisioning householders aligning their energy consumption to the production of local, renewable energy – and to do so in a more human, participatory and bottom-up fashion.

### 6.2 Design Visions of Future Energy Technology

As pointed out by Gangale et al. [17], the conceptualisation of household engagement in projects investigating future energy systems is predominantly informed and shaped by people with an interest in the energy sector. Moreover, these projects tend to envision consumer engagement through motivational factors such as environmental consciousness, reduction and better control of electricity bills [17]. Strengers' 2014 Interactions' article [54] conceptualises this empowered energy consumer as the "Resource Man" and critiques this conceptualisation as most people are not interested in monitoring and rationalising their energy consumption. Brynjarsdottir et al. [4] also discuss how only focusing on energy optimisation and utilitarian interaction aspects of these systems narrows the idea of sustainability problems and solutions.

We also saw the conceptualisation of consumer engagement embedded in the vision of the GOFLEX project resembles Strengers' "Resource Man" [54]. While the focus on designing interactions with the GOFLEX systems was based on valued usability and utilitarian interaction principles such as effortlessness, efficiency, and convenience, our study illustrates that households living with these systems are also motivated by different purposes. Most participants in our study welcomed these technologies into their homes and, in general, were joyed by the new information and playfulness the technology afforded. Our study also identified that new and innovative technology fosters experiential engagement as householders engage and tinker with features and information available through these technologies. This way of seeing engagement was not identified as part of the GOFLEX vision.

Other studies highlight that desires other than utility and environmental concerns are why such technologies are brought into the home [20, 30, 46, 59, 60, 64]. Together our findings suggest both alignments and misalignments between what designers of these technologies assume about the engaged householder and what householders are expecting from these technologies, and how they should co-perform in everyday practices [25, 37]. To better encounter household's expectations in the development of future energy systems, we see exciting opportunities for HCI researchers and designers to create interaction designs that move away from evaluating how effective, effortless, and convenient these environmental benefits may come about, and instead focus on the fun, playful and meaningful of experiencing future energy systems [7, 28, 34, 60]. HCI researchers and practitioners have a well-suited portfolio of tools, methods and approaches to engage in the designs of these technologies and better encapsulate the dynamics of everyday life [48]. Our findings, as summarised in Table 1 point to where such a departure may begin.

## 7 CONCLUSION

In the vision of future energy systems, it is often assumed that new and innovative technology will be beneficial for householders, as it will provide better control of energy consumption and thus enable the use of local renewable energy [9, 61]. However, introducing these potentially transformative technologies means we face a new future in our understanding of how people produce, buy, distribute, consume, and interact with energy [17, 63]. The design vision embedded in these future energy technologies often assumes that the householder will engage with these technologies as long as interaction is effortless, efficient, and convenient.

In this paper, we provide new aspects of what people expect and how they experience technology that trades energy flexibility on their behalf. We identified three design assumptions embedded in the vision of EU project and developed GOFLEX technology. We have summarised points of convergence and divergence that emerged from a questionnaire study with 167 households that participated in a field trial reflecting on their experiences of living with technology. Our study contributes to the future energy system field by providing insights on (mis)alignments between developers' design assumptions inscribed in energy technology and householders' expectations of future energy technology. We used these insights to discuss how human-centred perspectives can help bring design alternatives to align visions and human engagement in future sustainable smart energy technology.

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