RESEARCH-ARTICLE

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Adopting sustainable consumption practices in households is challenging due to the complexities of everyday life. Although eco-feedback technology supports people's environmental actions in households through the provision of feedback about resource consumption, people still find it difficult to use these systems in relation to their everyday lives. We present the results of a field study in which participants from 15 households used a mobile application, Eco-Garden, for three weeks. Eco-Garden provides information about household resource consumption and encourages sustainable practices at home. Our findings show how Eco-Garden encouraged members of the households to reflect, shift consumption practices, and support planning for future usage. Family involvement played a major role in driving social accountability and fostering sustainable habits. Our results show the gendered nature of domestic work, where women often take more responsibility for household management and sustainable activities. We noted goal-setting, self-motivation and an individual sense of responsibility motivated through Eco-Garden encouraged sustainable practices in households. We discussed how self-reporting and goal-setting features can enhance self-motivation and a sense of responsibility, encouraging sustainable practices in households. We suggest that future eco-feedback systems need to help bridge the gender divide in household sustainable activities while balancing comfort and consumption reduction.

CCS Concepts: • **Human-centered computing** → **Empirical studies in collaborative and social computing**; **Empirical studies in visualization**.

Additional Key Words and Phrases: Eco-feedback, Sustainability, Goal-setting, Self-motivation

1 Introduction

Sustainability has become a central concern in modern society, with an increasing emphasis on reducing household consumption and adopting environmentally conscious practices, as households are significant contributors to global carbon emissions [78]. To address these challenges, eco-feedback systems have been proposed, which are defined by Froehlich et al. [75] as "technology that provides feedback on individual or group behaviours with the goal of reducing environmental impact" (adapted from [38] and [52]). These systems offer individuals and households the opportunity to monitor and manage their consumption [33, 39, 63].

Mobile apps designed to provide eco-feedback have shown promise in engaging users by offering data visualisations, enabling them to track their daily consumption [42, 63]. They can provide accessible information on the consumption of specific appliances, and historical comparisons of consumption [39]. Setting realistic goals to reduce environmental impact is also found to be an effective strategy [45, 46]. However, the success of these eco-feedback systems depends not only on the clarity of the data but also on their ability to be integrated into the household's daily routines [60, 63]. Aligning these systems with everyday practices [28] is critical, especially when considering the diverse gender dynamics within households [10, 56, 60].

Furthermore, the balance between sustainability and comfort is often delicate in households, as individuals can resist making changes that seem to compromise their comfort, such as reducing heating or limiting the use of certain appliances [40, 70]. Therefore, eco-feedback systems should support households find practical solutions that align with their lifestyle while fostering deeper reflections on consumption patterns [62, 70]. By encouraging family members to participate in discussions about sustainability and hold each other accountable [60], eco-feedback systems can promote and support household's collective efforts toward sustainability at home [59, 62].

Eco-feedback systems have mostly succeeded in reducing consumption by 5–15% [9, 21, 75]. However, the engagement with eco-feedback could decrease with time, and eco-feedback is likely to be mostly appealing to those who are environmentally motivated [37, 55]. Also, most prior design technologies for houses are based on assumptions and have reported observing relapse behaviours and boomerang effects [23]. Additionally, sustainable HCI has emerged as a critical focus within the field of HCI research [5, 25]. Mankoff et al. [50] categorised sustainable HCI into two primary orientations: sustainability in design, which focuses on minimizing the environmental footprint of technologies, and sustainability through design, which seeks to influence sustainable lifestyles and decision-making. Persuasive technology, as highlighted by Tscheligi et al. [77], aims to inform users of the environmental impact of their actions and encourage pro-environmental behaviours. However, as Brynjarsdóttir et al. [12] critiqued, these approaches often rely on a narrow framing of sustainability and human behaviour, where designers determine what constitutes "sustainable behaviour" [12, 25]. This prescriptive nature can limit the usefulness of these systems and hinder the achievement of sustainability goals [12]. Rather than seeking to change individuals' attitudes and actions [64], recent studies highlight that sustainability challenges are deeply rooted in sociocultural practices [16, 28, 64]. Everyday practices such as cooking, cleaning, and laundry, consume resources and are shaped by complex social, cultural, and material factors [28]. Targeting isolated behaviours offers a limited perspective, as fostering sustainable practices depends on understanding the interconnected systems that sustain them [28].

This paper explores the potential role of a mobile app, Eco-Garden, designed to visually represent household consumption to facilitate sustainable practices within households. In line with previous work [26, 68, 74, 81], we constructed Eco-Garden to visualise electricity consumption, gas usage, and food waste. We report the results of a field study with 15 households that interacted with the Eco-Garden mobile app for three weeks. Our results present how the use of self-reporting data on the mobile app aided reflective practices [38, 39, 52, 75] in households, helping them to identify self-consumption patterns through family discussions and leading them to plan for sustainable practices. One of the key findings is how participants reduced consumption without sacrificing household comfort, rethinking the gendered roles and duties and individual sense of responsibility in their household sustainable actions, and how providing transparency in home consumption through the mobile app could avoid tensions in shared households. Furthermore, we present a number of challenges and opportunities to provide clear and intuitive data visualisations to communicate household consumption data in an understandable manner. This complements prior research on how a clear and pleasing visualisation of disaggregated data can enhance the understandability of household consumption [19, 33, 42]. Based on our findings, we discuss how self-reporting and goal-setting features on the mobile application can motivate consumption reduction [45, 46], how gender equality/balance is essential to support household sustainability [17, 53, 66] towards increasing

individual sense of responsibility within households, and how to reduce household consumption while navigating home comfort practices [40, 70].

2 Related Work

2.1 Eco-feedback Technologies

Eco-feedback technology has been researched in recent decades. According to Fischer [30], eco-feedback has been shown to be a successful strategy to encourage behaviour change and generate considerable reductions in electricity usage. Between 1987 and 2008, Fischer [30] examined five collections of articles that explored how eco-feedback affected electricity use. Following a study on 10 households using a mobile power meter, Kjeldskov et al. [42] reported that users found the ability to compare their use with other community members to be beneficial and that householders had a thorough understanding of their own usage. Furthermore, the fact that users can access their consumption from almost anywhere made the mobility component important as well [42]. Other research studies report on how much electricity is used by different appliances, different parts of the house, or even everyday tasks such as washing or meal preparation. Karjalainen [39] analysed different ways of presenting feedback on electricity consumption and found that users prefer presentations of costs (over a period of time), appliance-specific breakdown (information on what proportion is consumed by each appliance), and historical comparison (comparison with their own prior consumption). In addition, Costanza et al. [19] conducted a field study to find out if people could easily make a link between appliances and their daily routines. Their findings demonstrated that when tagging consumption, users would refer to the energy consumed by activity rather than by the appliance demonstrating users' understanding of consumption through activities.

Several researchers also attempted to design eco-feedback using persuasion; for example, Gamberini et al. [33] investigated the potential of using a mobile persuasive game to promote electricity conservation behaviours. This eco-feedback game offered consumption data based on appliances in the entire house in next-to-real-time. Four families played the game over the course of four months, and the results revealed that users continued to play it during this period, even if their daily accesses gradually decreased. The users explained the gradual reduction by claiming that they were becoming more familiar with the application and what it had to offer. Nonetheless, after an initial time of exposure to eco-feedback, there is a tendency for sustainable behaviours to relapse due to a decrease in the attention given to the feedback [55, 63].

2.2 Household Practices for Sustainable Consumption

Additionally, it is suggested that home comfort, which includes warmth, aesthetics, and emotional support, affects how much energy is used at home [27]. For instance, Kashimoto et al. [40] introduced an energy-saving device control method with the minimal reduction of user's comfort level. Many approaches for device control have been presented in the past (such as the use of sensors and timers to switch off appliances, analysis of consumption of devices through smart meters , and intelligent control systems to act on Heating, Ventilation and Air Conditioning) [15, 22, 34], but many of them failed to achieve notable energy savings without compromising comfort. Furthermore, gender dynamics in households are important to consider as mostly women are responsible for performing household duties [29] that can contribute to consumption such as cooking, washing, and cleaning. According to Strengers [75], households utilise water and energy for everyday activities such as cooling, showering, and laundry, which are influenced by institutional, social, cultural, and technical factors. For example, most research has focused on understanding individual consumption practices or supporting individual efforts to reduce consumption rather than understanding how the dynamics of collective households shape people's experiences and use of data-driven technologies [57, 58, 60, 61].

Therefore, it is necessary to have a deeper comprehension of household habits and collective dynamics to go beyond the technicalities of interventions [60, 69] and encourage sustainable consumption in the home

context [65, 74]. According to the practice-oriented view, domestic consumption is mostly invisible because of deeply ingrained social practices that take place in the home, where people participate in activities that share and consume resources (such as food, energy, water, etc.) rather than viewing themselves as resource users [10, 15, 56, 60, 65]. Thus, communicating information on consumption presented via the lens of practices should be more receptive to households [28] to further understand how the relationships within a household influence the use and everyday interactions with eco-feedback technologies.

2.3 Sustainable HCI and the Critique of Prescriptive Eco-Feedback

Within Sustainable HCI [37, 50], eco-feedback technologies have frequently been framed as tools for informing users and encouraging pro-environmental behaviour change [9, 21, 75]. However, critical scholarship has problematised the prescriptive logic underpinning many such systems. Brynjarsdóttir [79] argue that eco-feedback often narrows sustainability to measurable behavioural optimisation, positioning designers as arbiters of what constitutes 'correct' environmental action. This framing risks oversimplifying sustainability challenges and individualising responsibility for systemic issues. Practice oriented theory [16, 43, 64] offers an alternative analytical lens by shifting attention from individual attitudes to the sociomaterial configurations that sustain everyday consumption practices. Rather than targeting isolated behaviours, practice-oriented approaches examine how routines such as cooking, heating, and laundering are shaped by infrastructures, cultural norms, competencies, and material arrangements. This perspective challenges purely efficiency-driven models and opens space for sufficiency-oriented thinking—where the focus moves from continuous optimisation toward defining appropriate thresholds of consumption.

At the same time, critiques of individualisation caution that household-facing interventions may inadvertently reinforce the notion that sustainability is primarily a matter of personal responsibility, thereby obscuring infrastructural and policy-level determinants of consumption. Our research is positioned within this critical space. It draws on practice theory to foreground everyday routines rather than isolated behaviours, while also experimenting with reflective visualisation as a design method. However, as our findings suggest, tensions remain between efficiency-oriented goal tracking, sufficiency aspirations, and broader systemic constraints. By surfacing these tensions, this work contributes not only an intervention but also rethinking the design assumptions embedded within contemporary eco-feedback systems.

3 Eco-Garden: Designing to Encourage Sustainable Consumption Practices at Home

The goal of Eco-Garden is to visualise household consumption data to encourage sustainable practices at home. Eco-Garden combines a data sculpture and a mobile app that visualises household consumption for electricity, gas, and food waste. Taking a human-centered design approach, we started a project in October 2021 to investigate how eco-feedback technologies may be designed to encourage sustainable practices in UK homes. We have four phases in the design process: 1) understanding and exploring challenges of household consumption practices and identify design requirements [56, 59–61], 2) exploring the design space for eco-feedback technologies and data visualisations [62], 3) creating the first version of Eco-Garden and gathering user feedback, and 4) re-design the Eco-Garden prototype and conducting a field study [57, 58]. In Phase 1, we conducted a survey (22 responses) and 13 household interviews to understand practices, values, and factors influencing consumption [60], and how participants would want to visualise their consumption data [61]. We created low-fidelity prototypes during this phase to communicate the idea of data sculptures. In Phase 1, participants suggested the need to have an abstract visualisation without text or numbers to quickly understand consumption (preferably a physical object), along with a separate detailed view on a mobile device. Building upon the Phase 1 findings, we conducted 15 household design workshops in Phase 2 to explore the design space for an abstract physical data sculpture [62] and gather user requirements and preferences for a mobile app that offers views of detailed consumption. These

workshops identified design considerations for the sculpture and features for the mobile app such as showing granular data for home consumption, displaying charts for consumption, historical comparisons, and setting a target consumption. We found that participants did not wish to see the money they spent on consumption as it provides negative reinforcement. Participants identified electricity, gas, and food waste as the most important consumptions in their homes. As part of this process, we also identified design considerations for a physical data sculpture regarding size and location requirements, the need to make the sculpture abstract, and the need for child-friendly design in households. Details of the data sculpture are out of scope of this paper and will be reported elsewhere. In this paper, we report only on the iterative design of the mobile app.

Based on the findings from Phase 2, in Phase 3, we designed an initial version of Eco-Garden's mobile appa to visualise household electricity usage, gas usage, and food wastage (Figure 1). We developed the mobile app using the MERN stack (MongoDB, Express.js, React.js, Node.js). When the user enters the app, they see a home screen that displays the navigations to each view of the app. We added separate page views for electricity data, gas data, and food wastage for clarity and easy navigation. We track electricity usage per each devie using TP-Link Tapo P110 smart plugs. Users can check the gas usage on the gas meter and enter their daily gas usage on the app, and while doing so, they are requested to tick the activities they did during the day, such as having a hot shower, cooking, or using the heater (Figure 3). Similarly, we provided each home with a food weighing scale on which they can weigh their food waste. Users enter food waste on the mobile app while ticking which category of food went to waste that day (e.g., dairy products, bakery goods, fruit, vegetables, and fish/meat). Aligning with Karjalainen [39], we show daily and weekly consumption data for electricity, gas, and food waste through line and bar charts. The mobile application also display the disaggregated electricity consumption for each device, gas consumption for hot showers, cooking, and heating, and food waste for dairy products, bakery goods, fruit, vegetables, and fish/meat. We display electricity consumption in four ways (Figure 2): 1) hourly

(a) First version of the mobile app designed in Phase 3 of the research

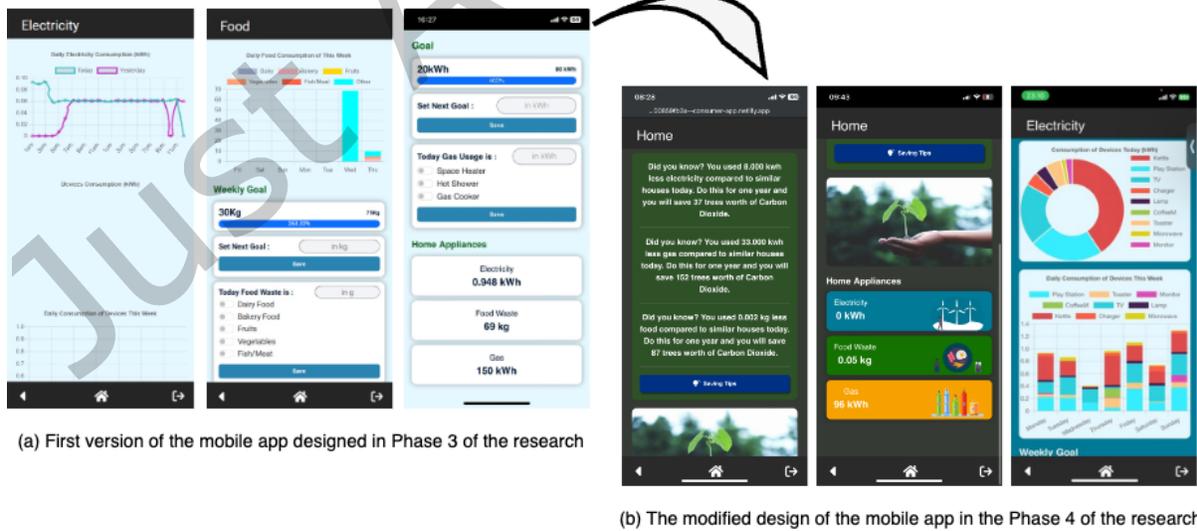(b) The modified design of the mobile app in the Phase 4 of the research

Fig. 1. Evolution of the mobile app through the phases of the research based on participants' feedback and suggestions: (a) in Phase 3 of the research we created a mobile app to get user feedback, and (b) in Phase 4, we modified the mobile app based on user feedback and created a completed app for the final field study.

Fig. 2. Information displayed on the 'electricity' page of the mobile app (one participant's consumption details). The mobile app display electricity consumption in four ways and users can set a weekly goal: (a) hourly electricity consumption in a line chart, daily electricity consumption of devices per each consumption practice (i.e. cooking, laundry, entertainment, work) in a doughnut chart, (b) daily electricity consumption for each device separately in a doughnut chart, and weekly electricity co vnsumption for all devices in a bar chart, (c) users can set a weekly goal and also view their consumption against the goal through a progress bar.

electricity consumption in a line chart, 2) daily electricity consumption of devices per each consumption practice (i.e. cooking, laundry, entertainment, work) in a doughnut chart, 3) daily electricity consumption for each device separately in a doughnut chart, and 4) weekly electricity consumption for all devices in a bar chart. Aligning with Locke and Latham [45, 46], we allowed for weekly goal setting. We added a progress bar for each page so that the user's progress is visible against their weekly goal.

In phase 3, we then conducted 14 household workshops to gather user feedback on the EcoGarden's app (e.g., ease of use, and understandability of the user interface). These workshops identified certain modifications to the mobile app in terms of changing the colour usage of the user interface to a more pleasing colour such as green, changing the colours of the charts for clarity, a chart to view the usage for consumption categories (such as cooking, laundry, entertainment, work), and addition of sustainability tips to make users are of ways to curtail consumption. Finally, in Phase 4, we modified and re-design the final version of Eco-Garden mobile app (Figure 1) by integrating the findings from Phase 3. Aligned with Rasmussen et al. [28], we added a chart to communicate electricity usage in terms of people's daily activities (cooking, laundry, entertainment, work). We also changed the colours used in the charts to add more separation for clarity and ease recall. We also added a separate section on
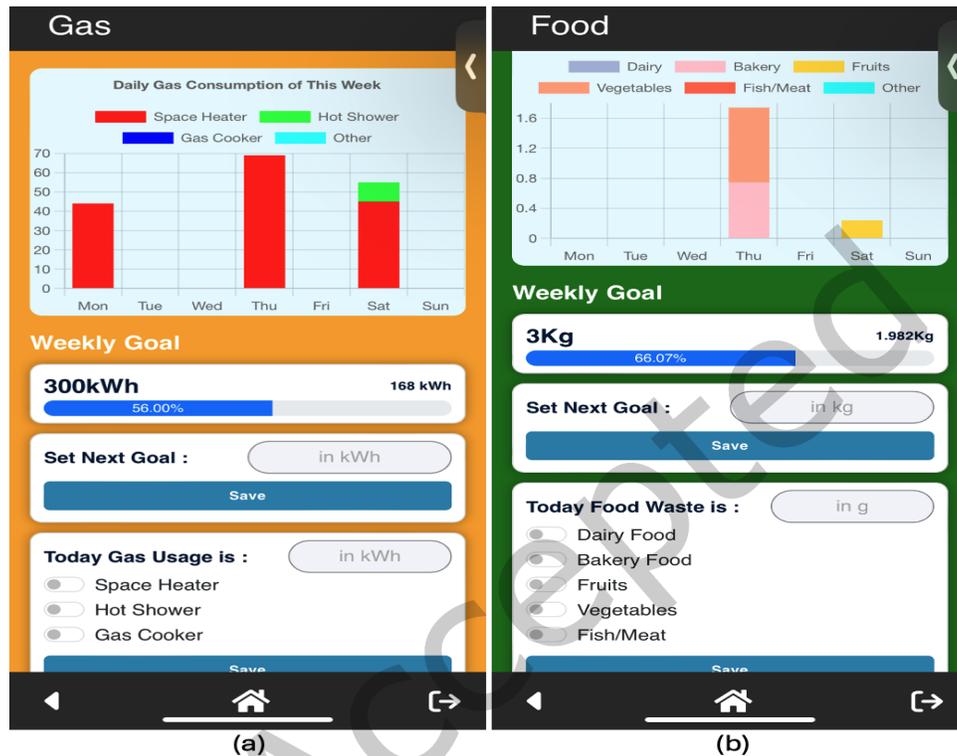
Fig. 3. Information displayed on the 'gas' and 'food waste' pages of the mobile app (one participant's consumption details): (a) we display the weekly gas consumption , and (b) we display food wastage throughout the week . User can set a weekly goal for both gas consumption and food wastage.

the app home page that leads to a separate view to read sustainability tips to curtail electricity use, gas use, and food waste (Figure 1 (a)). Further, we added labels on the main page regarding the 'number of trees saved' by each household based on the amount of carbon emission reduced due to their household consumption curtailment (Figure 1 (a)). We then conducted a field study with 15 households where each home used Eco-Garden (data sculpture and mobile) for three weeks. In the following sections, we report on the results of the final evaluation of the mobile app.

4 EVALUATION

We conducted the final field study in 15 households in Wales, UK, where each home used Eco-Garden for three weeks to investigate how it was perceived and its potential to encourage sustainable practices in a home context. Before the start of the study, participants were requested to read the Participation Information Sheet and sign a consent form. The field study was conducted between February and July 2024, with a favourable ethical opinion obtained from the ethics committee of the School of Computer Science and Informatics at Cardiff University (approval no: COMSC/Ethics/2024/001), and each household received a £25 voucher.

Table 1. Household's demographic information.

Household	Household Type[1]	Members in the house	# of children	# of participants	Age ranges	Gender. Male-M, Female-F
H1	SH	2	-	1	25-34	F
H2	SO	1	-	1	35-44	F
H3	SO	1	-	1	25-34	M
H4	NF	4	2	1	25-34	F
H5	SH	2	-	2	25-34	M, M
H6	SO	1	-	1	25-34	M
H7	SO	1	-	1	35-44	M
H8	SO	1	-	1	35-44	F
H9	SH	2	-	2	35-44	M, F
H10	NF	4	2	2	25-34	M, F
H11	NF	4	2	1	35-44	F
H12	NF	4	2	2	35-44	M, F
H13	SH	2	-	2	35-44	M, F
H14	NF	3	1	2	35-44	M, F
H15	NF	4	2	2	35-44	M, F

[1]Household Type (NF - Nuclear family, SH - Shared house between partners or tenants, SO - Single Occupant)

4.1 Participants

During the initial study in phase 1 of this research, we used our university social media group and mailing lists for participant recruitment. We invited participants from phase 1 to the current study in phase 4 of the research. Ten households (H1 to H10) with adults ranging in age from 18 to 54 years old from phase 1 participated in the field study (Table 1). In addition, we recruited five households through the university email network due to attrition of previous participants. Overall, our household participants had one to four people per household, including five single-occupant households, four shared homes between partners or tenants, and six family homes with children. Three of the participating households were all electric and they did not use gas (H1, H2, and H6). Although we did not directly involve children, we learned about children's experiences through their parents [71].

The study involved 15 households, a sample size consistent with qualitative HCI deployment research prioritising depth of engagement over statistical generalisation. Rather than aiming for representativeness, recruitment continued until thematic saturation was reached - defined as the point at which successive interviews yielded no substantively new thematic insights. The emphasis was on capturing diverse household configurations and practices to explore patterns of engagement and reflection across contexts. While the sample size limits quantitative inference, it supports rich, practice-oriented analysis aligned with the study's exploratory design aims.

4.2 Field Study: Procedure

we carried out climate-attitude surveys, pre- and post-study surveys on the experience with Eco-Garden, pre- and post-study interviews, and three weekly interviews with members of every household. At the start of the field study, we emailed participants and asked them to select a time that would work best to visit their household and set up the EcoGarden's system. During this first visit, we gave the participants an explanation of the field study's goals. Then, we gave an explanation of the Eco-Garden (data sculpture and mobile app). With the participants' permission, we then set up the Eco-Garden system in each household as well as the TP-Link Tapo P110 smart

plugs to capture electricity consumption of the specified appliances. First, we conducted a survey which had three sections: one was to capture participants' climate-related attitudes, second was to understand the curtailment actions taken at home, and the third section was to understand participants' first impressions of Eco-Garden. Second, we then conducted a 15-minute pre-study interview with the aim of further exploring participants' initial impressions of Eco-Garden in more detail. The selection and design of the survey Likert scale items were adapted from previous scales (see [60, 76]) to assess participants' attitudes towards climate change and curtailment activities practised in the household. At this time, households were reminded to set a new consumption target for the next week on the mobile app.

Third, we visited each household once a week to conduct a 30-minute interview to get weekly feedback on how participants felt about Eco-Garden, how they interacted with the system, whether or not everyone in the home collaborated with it, whether or not the system encouraged any changes to routines or practices, and their thoughts on the data presentation. Participants were instructed on how to enter data on their gas usage and food waste using the EcoGarden's mobile app. During these interviews, households were also reminded to use the mobile app to set a new consumption goal for the next week.

After three weeks, we conducted a post-study using a survey and a household interview with members of each household. The survey consisted of two sections. The first section was similar to the first and second parts of the pre-study survey: 1) captured climate attitudes and 2) understanding curtailment actions of the house. The purpose of reusing the first section of the pre-study survey was to identify temporal shifts in climate-related attitudes and curtailment actions taken at home. The first section of the pre-study survey was reused to discover temporal shifts in climate-related attitudes and perceptions of Eco-Garden. The second section of the post-study survey had three sub-sections: a) understanding households' overall experience with Eco-Garden system (data sculpture and the mobile app together), b) separately understanding the experience with the data sculpture and how well it fitted into the home (this part is out of scope of this paper), and c) separately understanding the mobile app and its use and experience. Household interviews were conducted to collect information regarding households' general experience, any changes in habits, and the usability of the system. In this paper, we shall report on the pre-study survey, sections 1, and section 2 (c) of the post-study survey, the results related to the mobile app in the qualitative interviews (pre-study interview, three weekly interviews, and post-study interview), and also the consumption data logged through the mobile app. The results related to the evaluation of the data sculpture and section 2 (a) and (b) of the post-study survey are out of the scope of this paper and will be reported separately.

4.3 Qualitative Data Analysis

All interviews were recorded and transcribed to conduct a multi-stage reflexive thematic analysis [6, 7] with the aid of NVivo (Version 1.7.1). In order to gain context and understanding, we started the process by getting familiar with the qualitative data. Initial codes were produced in order to gather feedback related to Eco-Garden, critically evaluating the impact of individual perspectives on code selection [6]. To help identify themes, we repeatedly went over the transcripts, generated codes, and sorted them eight times.

Thematic analysis was conducted iteratively across eight systematic passes of the interview transcripts. Initial open coding generated a broad set of preliminary codes, which were progressively refined, merged, and organised into four overarching themes that structure the findings section. Coding was conducted collaboratively within the research team. Emerging interpretations were discussed regularly, and discrepancies in coding were resolved through analytical dialogue until consensus was reached. This iterative and reflexive process aimed to strengthen the transparency of the qualitative findings.

Initially, we conducted separate analyses of the pre-study, weekly, and post-study interviews for every household. This analysis aimed to comprehend the overall Eco-Garden experience during the course of the study.

Second, we analysed each interview set with every household separately. This was done in order to determine how each household's use and engagement with Eco-Garden's mobile app changed throughout the course of the study. Third, we analysed the data for every week for each household that took part. The objective of the third analysis was to understand the system's temporality for every home over the course of each week. Examples of initial codes were 'clear and intuitive data visualisation', 'collaborative household discussions', 'self-reflecting on consumption', and 'navigating non-negotiable consumption'. All of the codes were then categorised into more general, mostly descriptive themes. When we realised that the overarching theme was related to how households negotiate their consumption practices through the data visualised by Eco-Garden, we rearranged codes into themes and revisited them. We read the data associated with each theme and considered the strength of support ensuring that themes worked both within a set of interviews with a single household as well as across all interviews for all households. Finally, the results were grouped into four major themes: 1) Understanding through Collaborative Exploration: Household Conversations and Family Teaching Moments, 2) Engagement with the Sculpture: Shaping Understanding, Attitudes, Motivation, and Practices over Time, 3) User Autonomy, Constant Visual Feedback, and Physical presence Transforming the Understanding of Consumption, and 4)Moving Towards Sustainable Practices: Shifting Consumption Perspectives in Everyday Life with Family Influence and Self-Motivation . In this paper, we only focus on the results of the fourth theme (the rest of the themes are reported separately). Related to the fourth themes, in this paper we present our findings under the following sub-themes: a) Enhancing Understanding through Clear and Intuitive Data Visualisation in Household Consumption, b) Evolving Consumption Habits Through Self-Reporting and Feedback: Realising Self-Consumption, Supporting Reflection and Planning Moving Towards Sustainable Practices, c) Encouraging Conscious Consumption: Self-Efficacy and Goal-Setting, and d) Rethinking Roles: Negotiating Responsibility and Transparency in Household Consumption.

5 Results

5.1 Survey Results

In this section, we report the results of our pre-study and post-study surveys. The pre-study survey had three sections: 1) climate-related attitudes, 2) consumption curtailment actions taken in the home, 3) first impression of the Eco-Garden system. The post-study survey had four sections where the first two were similar to the pre-study survey: 1) climate-related attitudes, 2) consumption curtailment actions taken in the home, 3) experience with the Eco-Garden system (both the app and the data sculpture), 4) experience with the data sculpture, and 5) experience with the mobile app. We used the same Likert items for the first two sections of both pre- and post-study surveys to understand participants' shifts in climate attitude. In this section, we shall report on the pre-study survey, and sections 1, 2, and 5 of the post-study survey.

In Figures 4 and 5, we present our survey results for the first two sections of each Likert scale item in both pre- and post-study surveys. For ease of comparison between pre- and post-study results, we have combined both into the same charts where 'a' represents pre-study result, while 'b' represents the post-study. For instance, I1a is the Likert scale item number one in the pre-study while I1b represents the same item in the post-study.

The pre-study questionnaire on awareness of consequences (I1a–I3a, Figure 4) indicated strong concern about climate change (M = 5.2, SD = 1.18). All participants agreed that climate change is a serious issue (20% slightly agree, 73% agree, 7% strongly agree), and 67% believed they could further reduce their household consumption. In the post-study, concern intensified: 73% "strongly agreed" and 27% "agreed" that climate change is a serious issue, and 94% agreed they could further reduce their consumption (I1b–I3b, Figure 4).

On personal norms (I4a–I7a, Figure 4, M = 4.63, SD = 1.24), most participants initially reported commitment to reducing energy and food waste (60% and 67%, respectively, across "strongly agree" to "slightly agree"). Similarly, 67% agreed they felt a bad conscience when overusing resources, while 20% disagreed. In terms of self-efficacy, 7% disagreed that they were confident making energy-efficient choices when purchasing appliances. Post-study

results showed a consistent positive shift: 100% of participants agreed (at varying levels) they were committed to reducing energy and food waste, and confidence in appliance choices improved, with 73% now expressing agreement and none disagreeing.

For curtailment actions (I1a–I8a, Figure 5), pre-study responses (M = 4.77, SD = 1.74) showed mixed engagement. Most participants regularly filled washing machines to capacity (87% at least "sometimes"), turned off lights in unused rooms (93%), and adjusted heating according to usage (80%), while fewer practised meal planning (20% never) or washing laundry at lower temperatures (7% never). Some unsustainable habits persisted, with 13% leaving TVs on unnecessarily and 21% leaving heating on in unused rooms. Post-study responses (M = 4.61, SD = 1.57) indicated modest improvements: the share who "always" meal planned rose from 0% to 27%, and those who "always" filled the washing machine to capacity increased from 33% to 40%. However, some lapses remained: those who "never" switched off heating when leaving for holidays increased from 13% to 20%.

Perceptions of Eco-Garden before use were largely favourable (Figure 7). Eighty percent believed the system would blend into their home and 87% thought it would support them in reducing consumption. Over half agreed they would recommend it to others and use it long-term, though 7% strongly disagreed that most people would learn the system quickly. Post-study, evaluations of the mobile app were very positive (Figure 6). All participants found it useful, straightforward, and desirable for household sustainability, and 80% described its interaction as intuitive. All indicated they would continue using the app and recommend it, though 20% slightly disagreed that functions were well integrated. While 80% believed the app could be learned quickly, 34% felt the "number of trees saved" metric was not useful, and 27% disagreed or strongly disagreed that the sustainability tips were motivating.
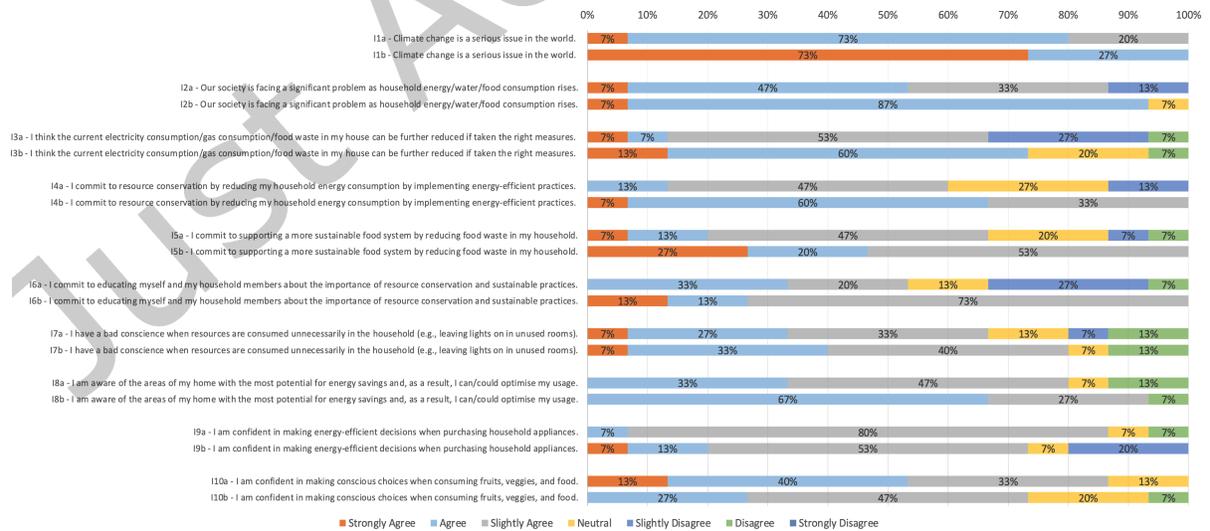

Fig. 4. Survey responses given via the Likert Scale survey. Statement rates are shown on the rows, with the total percentages of participants responding negatively, neutrally and positively to the statements overlaid on the stacked bar graph. Pre- and post-study results are displayed together where letter 'a' represents pre-study questions, while letter 'b' represents the post-study.
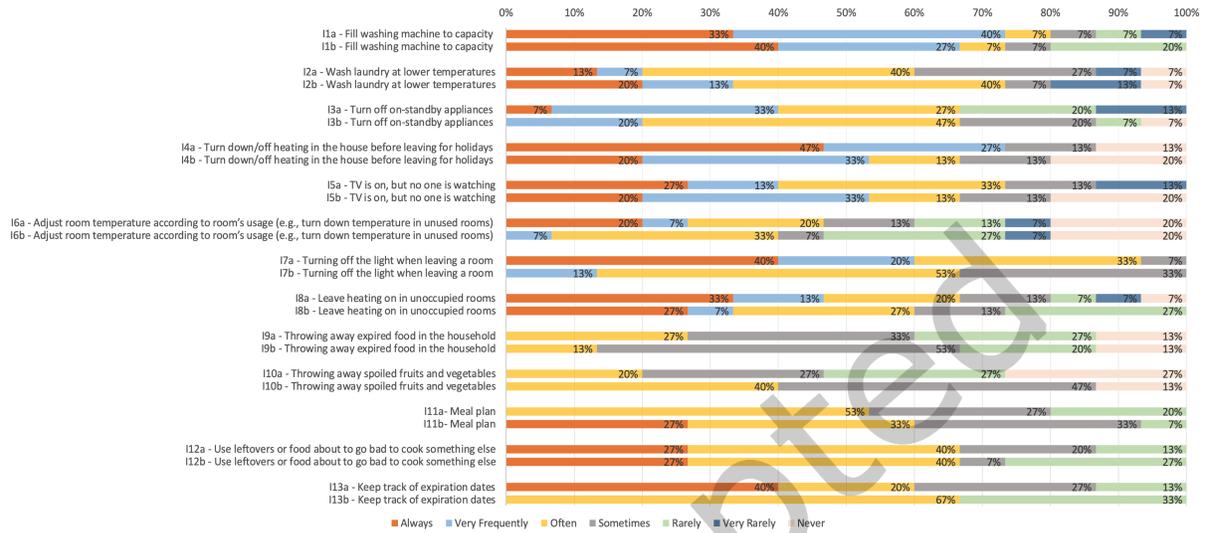
Fig. 5. Pre- and Post-study survey responses given via the Likert Scale with statements for curtailment actions carried out in the household. Statement rates are shown on the rows, with the total percentages of participants responding never, very rarely, rarely, sometimes, often, very frequently, and always to the statements overlaid on the stacked bar graph. Pre- and post-study results are displayed together where letter 'a' represents pre-study questions, while letter 'b' represents the post-study.
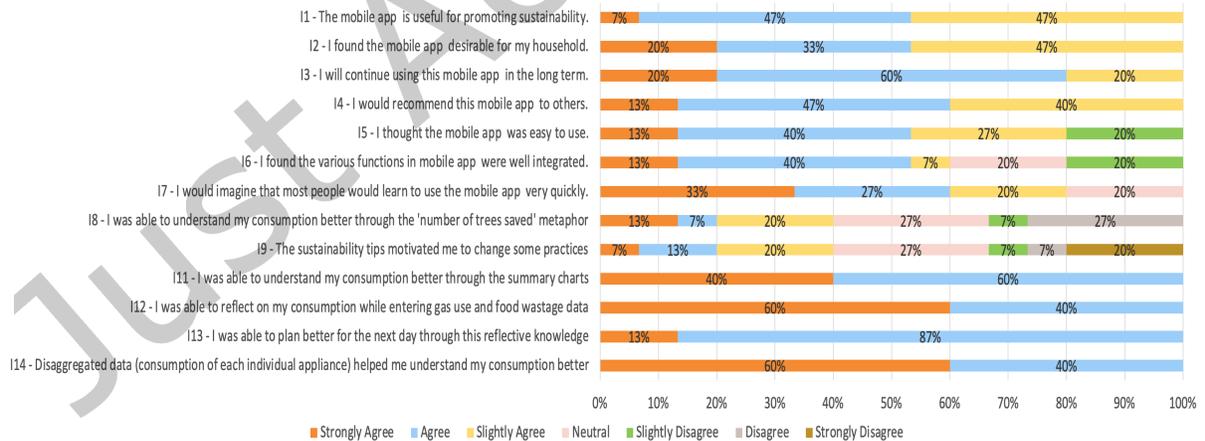
Fig. 6. Post-study survey responses given via the Likert Scale with statements related to the Eco-Garden's mobile app and its features. Statement rates are shown on the rows, with the total percentages of participants responding from strongly agree to strongly disagree to the statements overlaid on the stacked bar graph.

5.2 Recorded Consumption Logs

The recorded electricity data displays a gradual decline in consumption during the three weeks in household H1 from 1.29kWh in the first week to 0.55kWh in the final week (Figure 8). A similar electricity usage pattern is seen
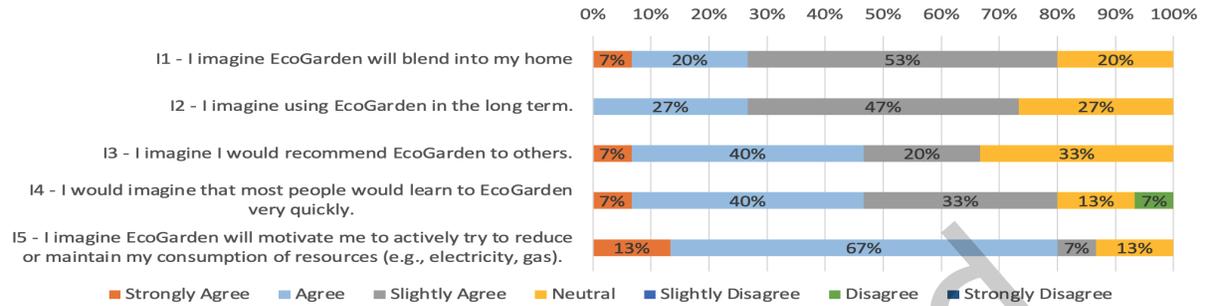
Fig. 7. Pre-study survey responses given via the Likert Scale in the pre-study with statements for envisioning the use of Eco-Garden system. Statement rates are shown on the rows, with the total percentages of participants responding from strongly agree to strongly disagree to the statements overlaid on the stacked bar graph.

Table 2. Weekly goals for electricity, gas, and food waste set by each household for the study duration of three weeks.

Household	Electricity (kWh)			Gas (kWh)			Food Waste (g)		
	Week 1	Week 2	Week 3	Week 1	Week 2	Week 3	Week 1	Week 2	Week 3
H1	3	3	2	-	-	-	300	100	50
H2	20	15	13	-	-	-	500	600	650
H3	28	28	25	170	175	170	-	-	-
H4	20	13	10	500	250	220	500	250	250
H5	25	12	12	500	250	240	250	240	280
H6	15	30	28	-	-	-	-	-	-
H7	8	8	8	100	90	85	-	-	-
H8	8	18	20	-	-	-	100	100	100
H9	10	15	10	300	200	250	1000	650	500
H10	5	4	2	500	400	300	800	600	450
H11	10	15	10	200	200	150	200	400	450
H12	10	8	8	250	250	200	400	500	450
H13	15	13	12	200	180	180	500	500	400
H14	25	22	18	250	220	200	1000	750	800
H15	10	10	10	200	100	100	200	250	350

in households H2, H3, H4, H7, H8, H10, H13 and H14. However, certain households show an increase in electricity consumption. For instance, household H6 has increased consumption from 18.8kWh to 38.9kWh by the third week. Household H2 displays an increase in electricity usage in week one (61.4kWh). They explained that their electric heating fan had been switched on all week, which caused higher overall usage. While these participants were unaware that the heating fan was using a large amount of electricity, the Eco-Garen mobile app helped them understand the consumption per appliance. This helped them strategically reduce the usage of the heating fan in the second week. Households H1, H2 and H6 did not use gas in their households, therefore, their electricity consumption could have been higher than other participants. While H2 and H6 displayed high consumption, H1 had very little electricity usage during the three weeks (1.29kWh, 0.69kWh, and 0.55kWh, respectively, for each week).

Households H4, H8 and H10 had high gas consumption, especially in weeks 1 and 2, in comparison to the other participants (Figure 9). All three households had similar gas usage in week 1 (95kWh in H4 and H8, and 96kWh in H10). While H10 remained at 96kWh usage in week 2, H4 reduced their usage to 63kWh and H8 used 88kWh. However, in week 3, all three households (H4, H8, H10) reduced their consumption to 32kWh, 75kWh, and 57kWh, respectively. Households H3, H5, H10, H12, H13, H14, and H15 also displayed a gradual reduction of gas usage over the course of the three weeks. Out of the households with children, H4 and H10 showed the highest gas consumption. Further, households H1, H6 and H7 had zero food waste in all three weeks (Figure 10), while H10 recorded the highest food waste (2.137kg in week 1, 2.347kg in week 2, and 2.169kg in week 3). Most households have gradually reduced their waste over the three weeks (H2, H3, H4, H5, H8, H11, H12, H13, H14). However, H15 displayed a gradual increase in their food waste from 138 grams in the first week to 244 grams in the final week.
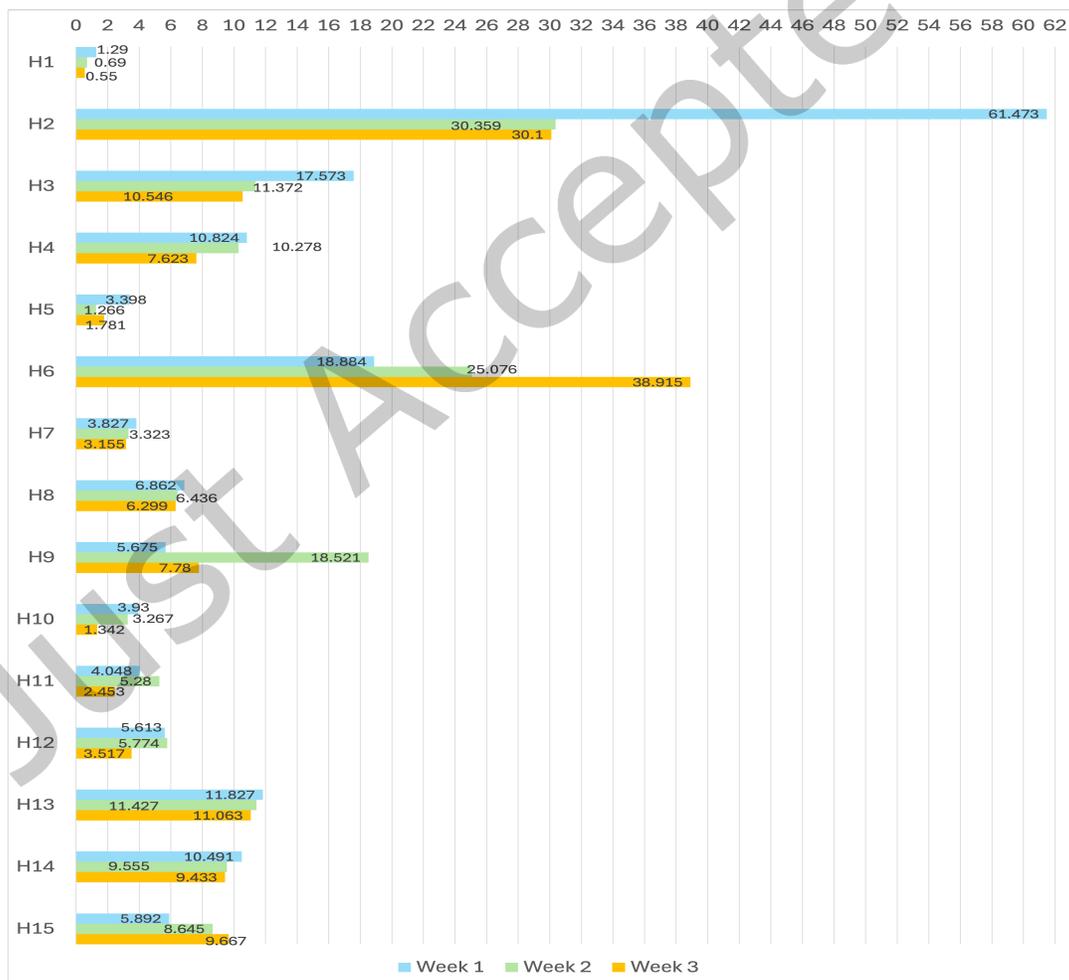

Fig. 8. Electricity data recorded from each household for the study duration of three weeks. All values are in kilo-watt hours (kWh).
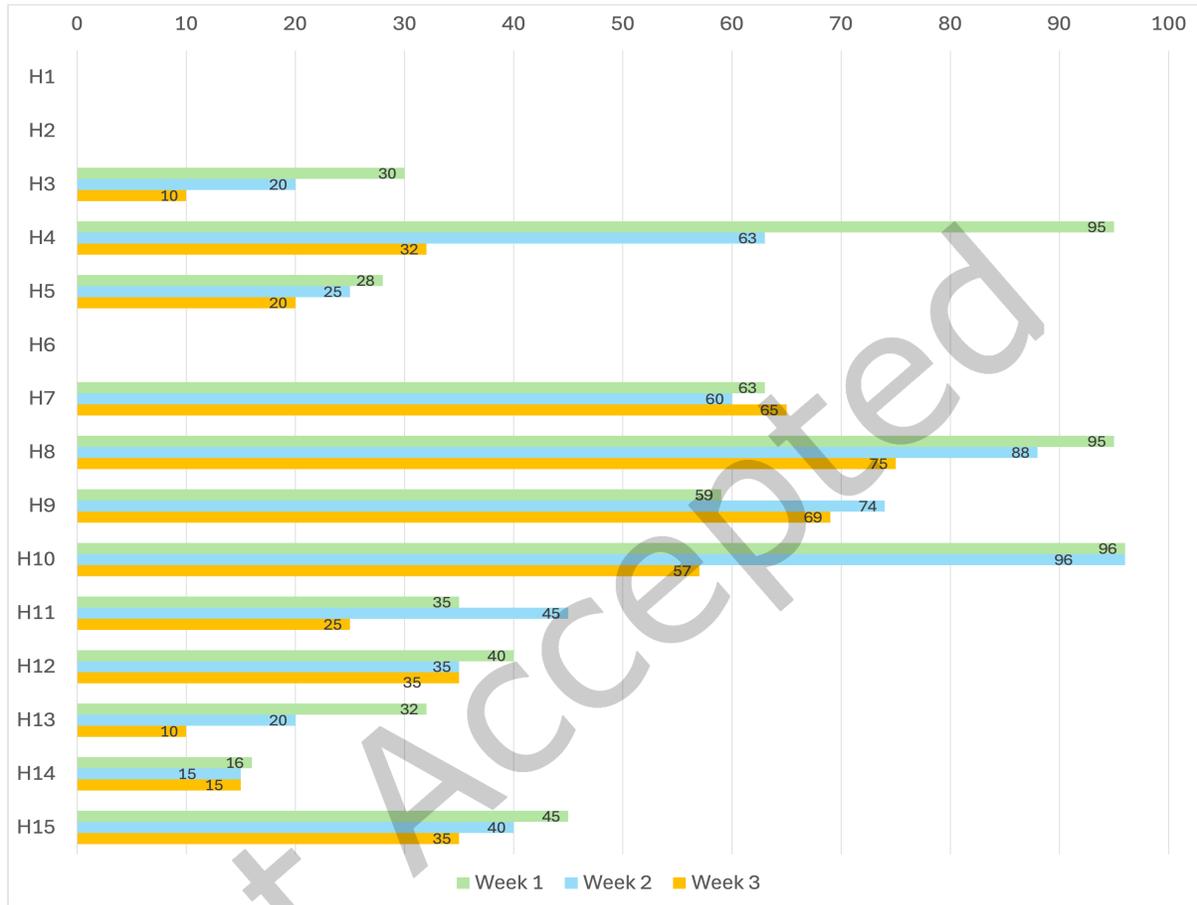
Fig. 9. Gas consumption data recorded from each household for the study duration of three weeks. All values are in kilo-watt hours (kWh).

The weekly goals set by the households for electricity, gas, and food waste display that the majority of the participants have attempted to gradually reduce the goals (Table 2). For instance, looking at the electricity goals , household H10 has gradually reduced their electricity goals from 5kWh in the beginning to 4kWh in the second week to 2kWh in the final week. Although household H2 has reduced their electricity goals from 20kWh to 13kWh from the beginning of the study to the final week, their consumption went beyond the goal in all three weeks. Similarly, even though H6's goal attempted to further reduce from 30kWh in week 2 to 28kWh in week 3, their consumption went beyond the goal for the final week (38.9kWh). Most households were able to stay within the goal for their weekly electricity consumption (H1, H3, H4, H5, H7, H8, H10, H11, H12, H13, H14, H15). However, the consumption of certain households was much less than the intended goal for each week (H3, H5, H8, H11, H14). In particular, H3 set electricity goals as 28kWh, 28kWh, and 25kWh for the three weeks, their consumption was 17kWh, 11kWh and 10kWh, respectively.

Fig. 10. Food waste data recorded from each household for the study duration of three weeks. All values are in grams (g).

5.3 Qualitative Findings

In the following subsections, we report the findings related to the mobile app of the pre-study, weekly, and post-study interviews. We report households' experiences with the visualised consumption information on the mobile app and varied perspectives related to household responsibilities, self-motivation, comfort, and engagement with the mobile app.

5.3.1 Enhancing Understanding through Clear and Intuitive Data Visualisation in Household Consumption.
Household H11 mentioned that the app breaks down complex information into a form that they can understand in a user-friendly interface: *"It's nice to see how it's broken down and it's not overly busy. It's quite simple to get around. I think one of the things is always that there's maybe too much going on but in this app, it just does what you need it to".* Further household H10 explained that the app was helpful in understanding what causes unnecessary usage in their home and planning towards adjusting their consumption habits: *"It was useful to monitor my consumption and to know what exactly I should focus on and then based on my monitoring of the consumption, I found out which device basically uses more energy in my house and then what kind of food I usually get rid of a lot. And then based on the visual data, especially on the app, I adjust my eating habits".*

Household H6 compared the charts in the app to their energy supplier's application to highlight the clarity provided by the app in visualising data: *"My energy provider only really gives this sort of daily chart. I do appreciate that the day by day on this app has splits for the different items. I love that. Sunday is my favourite day. Like I can see that I use like 1kWh on my rice cooker cause that's when I was prepping all my meals for the week. And then I*

use 4 1/2 kWh on my computer because I was on it throughout the day. But I used a little bit, you know 0.3 on the fridge. Being able to compare that day by day - so whilst my energy supplier shows that day by day in just a bar chart but they don't have any variation. It's just a bar chart, bar chart, bar chart for everything. Whereas as I said, I appreciate being able to see the bar chart version for the day, but this sort of line chart for the hour by hour, because then rather than just comparing like this bar goes here and this bar goes here, you see the little line connecting the hours showing there is a rapid increase in this hour versus a very, very slight increase in that hour."

Further, household H6 appreciated the usage of different colours in the charts to display different appliances (for example fridge, microwave, oven, TV, etc.) and categories (for example entertainment, laundry, cooking, etc.) highlighting the it gives clarity compared to the app provided by their energy supplier: *"I like the different graphs that pop up. They're colouring is nice and easy to see. The number of times I've seen graphs with my energy suppliers - those graphs are just the most difficult things to look at and understand because they use dark blue and lighter blue and medium blue and ocean blue. They're all too similar in colour. So, having bright pink, cyan, blue, and green as the different colours like in your app, I think it's super beneficial there. For the goal, the progress bar will fill up - it's a nice easy way of seeing a very similar thing to the physical object. Setting the next goal is simple and easy to use".* Household H10 commented on their engagement with the app over the three weeks: *"I used the app around 6 times a day in the first week. Then it reduced a bit to like twice or thrice a week. Because I had learnt what I wanted to learn at that point. This week (week 3) I only use it around once a day when I want to see my usage. I still use it when I want to know my consumption."*

Household H9 also explained that they realised that the kettle uses more electricity than the TV although they watch the TV for more hours than boiling the kettle: *"Last night I got on the app to see how it compares to using the TV for the time that we've used it and comparing it with how much the kettle uses. Seeing it kind of spelt out that actually the kettle is using more, even though we only boil it like maybe once or twice a day, that's using more power than my TV which is on for two to four hours in the evening. That's really eye-opening. I had the coffee machine on yesterday as well, so it's the first time that I've seen how much power a coffee machine uses and then compared that to the kettle".* The household was also planning to experiment with the settings of their PlayStation in the second week: *"I noticed on the app that my PlayStation uses a lot of power. I was comparing it with the kettle on the app. But I haven't even used it this week. I need to check its settings or something to see what's going on".* In week three, they explained that they managed to reduce its consumption by changing the settings: *"I remember us talking last week about the PlayStation and seeing how much power that was using, even when I wasn't using it. I did actually go into it last week and I changed the power setting. I've changed it so it now fully switches off and it turns out I had it on standby mode. We used it this week, and it looks much lower than it did previously, where it was kind of competing with the kettle every day and for the amount that was used despite not being played. And I also had the habit of double boiling the kettle and I changed in week 1 itself. This is helping me change my habits over the weeks."*

Household H6 further explained that it was difficult for them to distinguish between the weekly and monthly usages reported in the energy provider's application. They mistakenly thought the monthly usage reported by the energy provider was weekly usage. This led to them setting a very high goal for the first week in the Eco-Garden app as they took the value provided by the energy provider as a reference: *"this could be that I wasn't able to interpret my weekly usage data from my actual energy supplier. I think I've overstepped the goal by far because apparently this week, Sunday through Friday, I'm only at eight-kilowatt hours this week. I mean we set it to almost nine times that number. So maybe I accidentally set it as a monthly usage. The problem there is I was looking at my energy supplier's app, clicked on my weekly total, and just used the number that my energy supplier told me, as my weekly goal for week 1. An important point there, evidently my energy supplier is either lying to me or their website is too difficult for me to comprehend in comparison to this app."*

5.3.2 Promoting Household Discussions and Engagement with the App.
Households H4, H10, and H15 mentioned that they regularly engage with the app: *"I keep checking it every hour.*

Overall my experience is so good. The app is so attractive and so easy to enter the data and so easy to read the data. I like the colours and sorting. It's informative." Households H3 and H14 mentioned that they continuously look at the charts multiple times a day: *"I keep checking the charts at least like six times a day and just showing my kids the charts because you know it simplifies the presentation of the data. Then my kids ask me, 'What's the most used device?' and then we compare different days. Then we say 'during the weekends we consumed more than weekdays because you're at school all day'".* Household H5 mentioned that although he had many apps on his phone, he usually checks our mobile app often: *"I have many apps on my phone, and I forget about them. But this app, whenever I throw the food in the bin, I remember that I have to measure in the app and that's a good connection I have with the app".*

We came across household H7, where a male single-occupant lived, while his wife and family and his parents lived in his home country. He had discussions with his wife and brother back home regarding Eco-Garden. Initially, he was sure that he produced lesser food waste and was careful with the use of electricity. However, his wife pointed out that he sometimes wasted food when they were living together: *"I was thinking I could go zero with food waste. But my wife was saying, 'you do waste food; you will say it has been more than five days, we should throw it'. I was proud that I never waste food. But she saidI wasn't".* He further described that his brother explained that he was careless with electricity consumption: *"So even my brother was also saying that 'no, you're very careless with electricity. When you were living with us, you always kept your AC on. We need to switch it off'. I'm also using a lot of electricity for the fridge. My brother told me the fridge might be very old, so maybe if you are continuing to live in the UK, you should ask for a replacement. I will say overall I was very happy with them telling me those and we had very good discussions".*

5.3.3 Evolving Consumption Habits Through Self-Reporting and Feedback: Realising Self-Consumption, Supporting Reflection and Planning Moving Towards Sustainable Practices.

Shifting Consumption Practices at Home Following the Feedback from Eco-Garden. We came across household H2, which attempted to trial with the household appliances according to the knowledge they had gathered from external sources: *"When you told me the system would reset on Sunday, I started to test the movement. So it was around 1am when I noticed that it had slowly moved. But today I turned on the heating fan around 1pm and bee started moving very fast. I realised the heating fan uses so much electricity. I think the electricity prices go down from around like 7 in the morning until 12pm and then from 1am at night until 6 in the morning. Sometimes I just turn on the heating fan from 12am until 3am, because I usually stay late. So now this is what I do as a practice - switch on the heating fan late at night to reduce my usage. I'm not sure whether that's true but that's what I've heard".*

Household H15 had wasteful habits which they were trying to reduce: *"I have this habit - I turn on the gas for cooking, and I keep the oil to be heated and then do washing or something. Then the oil continues to heat. I started to not do this."* Household H7 mentioned that their habit of keeping all the lights in the house switched on, has reduced due to Eco-Garden: *"I always keep all my lights on everywhere. But this week, from the second week, I always stop. I have not switched on, so I try to maintain that habit and that is a good thing in me now".*

We came across household H6 which was a single-occupant home. H6 mentioned in week two, that they had the habit of leaving the rice cooker on the 'warm setting' for a while. By week 3, they had stopped doing it: *"a really small thing that I tried was last week... when I was cooking food in the rice cooker and it just flick to warm just after finished cooking. Then it just keeps it warm. I usually just keep the food warm until I finish prepping other food. What I did this week was I did all the prep beforehand so that the instant it finished cooking I could turn it off and then, bring the rice up, bring the vegetables out and everything like that. When I'm cooking now, I'm setting aside some time so that the instant that cooking is done I can prep my meals. I don't have to leave the rice cooker on for an extra 30 minutes to an hour whilst I'm finishing all this other stuff so the rice stays warm."* H6 further described that self-reporting the food waste was an eye-opening activity to realise how much was wasted: *"physically the act of*

going through and measuring it (gas and food waste) really impacted me of going 'oh wow, that's a lot more than I thought it was'. If it was just sort of automatic, if I just threw it in the bin and it automatically got added to the app, and I didn't have that manual aspect of having to weigh it myself, I think it would have detracted from that impact."

Household H7 mentioned that they were motivated to move towards zero food waste: *"although I rarely waste food, at least these two weeks it was a challenge for me. This week, I was very happy to see that I did not waste a single item even. There were some beans in the fridge, it was not too old like it was, I will say five to six days old, but I checked it and it was good and I cooked it yesterday. I think it was a good indication and for me it was a target that I will go for zero waste."* Household H3 mentioned that *"I don't see a difference in my food waste because I already care about food so much, so I try to freeze any leftovers or something, you know. So my behaviour towards food consumption is still the same. But I definitely prepped a lot more meals this week, and I bought all of my food beforehand. I always buy sort of frozen foods or if I have fresh foods then they get eaten immediately"*.

Investigating and Comparing Household Consumption Even Beyond the Eco-Garden System. We came across household H9 who explained that they were encouraged to look at the manuals of the electrical appliances at home which were not connected to the Eco-Garden system: *"even the stuff we weren't measuring through your system, I was going back and having a look at the electricity consumption of things and thinking can I get that information from somewhere else? Can I look in the manuals? I never looked at manuals before to try and figure that out. So there's kind of that side of it where it was definitely encouraging me to think more about how do you reduce. I suppose over the three weeks it has made me go back and look at the manuals for some of our gadgets that are the white goods... So although it's not being tracked in your system, we have gone and looked up and thought of the Eco setting on the dishwasher - is that actually the most economical?"*

Similarly, household H6 read on the internet on how best to operate a washing machine to save energy and trialled with the device settings: *"Especially for the laundry, I took a look on the Internet of how much electricity it uses with and without the Eco mode, and I did a little test. I couldn't turn on Eco mode when I was doing my jeans. So I was checking how much electricity it uses when I wash my jeans compared to washing all my jumpers because I turned the Eco mode on for the jumpers and everything else, and it was quite a large difference. I'll be making sure that I've got Eco mode on every time that I can now because of that. I have turned down the amount of time it takes to dry my clothes as well as the laundry. I've reduced the amount of time of dryer because advice on the Internet says that that's a really good way to save your electricity usage and make sure that you're not having damp clothes come out at the end of it".*

Navigating Non-Negotiables, Daily Routines, and Achieving Usage Reduction Without Sacrificing Comfort. We came across household H4 who mentioned that the electricity consumption of the fridge was non-negotiable, therefore, as a practice, they removed the icon for the fridge's consumption on the app when viewing the device-wise usage: *"I don't know if having fridge would be applicable because the fridge is working 24/7. While other devices are not. I would rather not have the fridge as part of the app in the future. Because actually, I cannot do anything about it unless I'm gonna buy a new fridge. I need to consider the quality of the fridge and so on. But since I have the fridge already, there's no point in knowing how much it consumes".* They further mentioned that they only use the appliances when they absolutely have to: *"I don't use the kettle unless, of course, I need the kettle. I have to use the charger, I have to use the air fryer."*

However, household H6 compared their non-negotiable use with the negotiables and was reflecting on how they reduced the use where they can: *"I just think it's kind of funny to see because there are times where I have to use that much electricity like if I have a meeting from sort of five till seven on Thursdays. I can't stop using my computer halfway through the meeting to reduce my electricity usage. But how does that then compare to my average random usage of me using my computer? I'm using just as much when playing video games or watching a movie. I sometimes forget and leave my desktop on while playing a video game. So I turn it off now".*

Household H10 explained that there were certain tasks that they wanted to do at home, however, when they exceeded the gas consumption target in week 2, they thought how to do those tasks without affecting the daily routines: *"when the gas exceeded the goal, I started to think. With my usage of some of the electrical devices, I was also a bit stressed out. I am just thinking about how I can reduce my usage. I really need like my coffee every morning, I need to heat the food every afternoon. So how can I reduce without affecting my daily routine? The prototype and the app were making me think this. So I did a change this week. Usually when I heat up the food, I put the food in a plate for me and then a plate for my husband, a plate for my daughter, a plate for my son. And then I heat each one on its own in then microwave. This week I put my kids and our food together and then I heat them up one time. Then I took it out of the microwave. Then I put their food each plate separately. So I use the microwave only once. Also, with the kettle, I usually only prepare my coffee in the morning, and then my husband comes, and he prepares his coffee. So this week we prepared our coffee together. So we only turned on the kettle once. So we did these actions this week because we were thinking, why do we need to turn it on two times? And learn we could all eat and enjoy the meal."*

Household H8 discovered that by turning their heater on and off more frequently rather than leaving it on continuously, they could maintain a comfortable room temperature while significantly reducing electricity usage. This approach allowed them to achieve the same level of warmth in their room but with less energy consumption, highlighting a practical strategy for energy efficiency that does not compromise comfort: *"Turning it on and off, keeping it on and turn it on and off more regularly really doesn't change the room temperature much. I still get a warm room and a nice room. But with less electricity usage".*

A Case of Retrospective Reflection on Efforts to Reduce Consumption. The Eco-Garden system made Household H9 reflect on how their consumption practices changed through the last year, although they did not use it at the time. They said that they changed many practices last year, hence, now there are only a few things left for them to adjust. They said that the Eco-Garden has helped them realise this change in their practices over the past year: *"in terms of electricity usage, I don't think it's really made us change things much, but it has probably been more of a reflection on how our lives have changed in the last year. We've been saying in the new year to read more and use screens a little bit less and all that. So our electricity usage is lower than it might have been a year ago anyway, and this system highlighted that it happened."*

Eco-Garden Encouraging Future Planning of Household Consumption and Long-term Use. Eco-Garden also encouraged household H9 to think of retrofitting their home to save electricity: *"I suppose the app highlighted stuff that is maybe not unfamiliar to us but we've forgotten, like we know we have a big cold and drafty house and that requires a lot of heating to get it to a livable temperature. Some of the stuff we're already doing was putting reflective foil behind the radiators. It has made me think that maybe I need to get back on that more quickly, and we have some radiators that we think need replacing and power flushing. This has made me think a little bit more urgently about that."* Additionally, household H10 mentioned that with long-term usage of Eco-Garden, people will develop a habit of reducing consumption: *"now after using the device for three weeks, I feel that with log term use people will develop a habit so they will continue using this habit because now 'we are using this much, this is more so we need to reduce it' and so on then they will continue doing that habit".*

How Existing Tracking Practices Facilitated the Use of the Eco-Garden App The husband of household H9 also related the act of entering their food waste and gas usage on the EcoGarden mobile App to how he used to track his food consumption on a fitness app to lose weight. He explained the different thoughts between him and the wife regarding self-reporting data: *"She thinks I'm crackers. I enter gas data into the app and I track electricity. I used to do calorie counting on my fitness pal app literally 12 years ago entering every meal into your app and all. I did that for two or three weeks, and it really quickly highlighted how bad some toast was for me, then I cut down on my cheese on toast, and as a result, I lost weight. I was explaining this to her and she thinks entering data is a lot of work. I understand though, she already does a lot of housework anyway".*

5.3.4 Encouraging Conscious Consumption: Self-Efficacy and Goal-Setting.

Influencing the Motivation of Participants through Goal Setting and Self-Efficacy. We came across household H8 where a female single-occupant lived. In the initial interview, she mentioned that she would not engage in reducing consumption as all her bills are included in the house rental. Therefore, she did not have any financial benefit from reducing usage. However, in the week 1 interview, she mentioned that surprisingly, she had attempted to be more sustainable with the usage of electricity and gas in order to prevent from passing the weekly target. She explained that the motivation to reduce usage was triggered by the weekly target and the personal need to stay below that: *"even though I really didn't think it would change my behaviour because my bills are paid, I didn't want to go above my goal. I really thought this was more or less an environmental awareness or an economic awareness thing. But I would relate this to more like my behaviour. I'm really not thinking about the environment when I don't wanna pass the target. It's not about the environment, it's about me. I do not wanna pass that target. It helps the environment, yes. But genuinely, that's not the first thing that comes to my mind when I try not to past that target."*

From Carelessness to Conscious Living. Household H8 further went on to explain that if she wanted to go beyond the target, she could as there were no penalisations. However, from the initial interview to the week 1 interview, her behaviour changed from not caring about the consumption to wanting to stay below the weekly target: *"I know it's not a requirement, I can still go beyond the goal. I still have that option. It's not like it's the ultimatum. Nobody's stressing me out. You're not stressing me out. All you're doing is just visualization. Here's what you use and the rest is up to me. And it's my responsibility. My bills, I pay it. You don't pay it for me. It's not a stressful thing. But I don't want to go beyond the target. This visualization and constant feedback has made me more aware of my usage. The first thing I thought when you set up the system was that I will definitely go beyond because I really don't care. But somehow, my behaviour has changed to the point that I don't wanna go beyond. This really proved to me that more of a human behaviour type of thing works rather than money or environmental awareness. You don't have to provide that much environmental awareness to everyone. But that constant feedback would do the job."* Discussing the mobile app, households H2, H6, H7, H8, H11, and H14 also mentioned that they were feeling happy and proud about their reduced usage that occurred without external incentives: *"(while looking at the app) my last week electricity was 18.5, and this week it's only 3.3. I think it had to go down so much. Oh! I am so proud. You know, there's no specific reward for this. You know you're not paying me if I use less. My bills are paid already, so my bills are not gonna get any less. But that satisfaction and pride are just so good. Put in five (doing a high-five with the researcher)".*

5.3.5 Rethinking Roles: Negotiating Responsibility and Transparency in Household Consumption.

From Women's Responsibility to a Shared Responsibility: Division of Labour and The Influence of Gender for Sustainable Practices. We came across household H9 where the husband and the wife lived. The husband mentioned that their household was a traditional home where they considered the wife of the home responsible for the use of most electrical appliances, for example, in the kitchen, and also food waste. Therefore, they saw the act of consumption reduction as a solo responsibility of the wife. However, due to the wife's workload, she was unable to manage and track the usage of both gas and food waste. Thereafter, they came up with a system together where the husband tracked the gas usage while the wife reported the food waste while cooking: *"We're not nontraditional in that my wife has a lot of mental load that tends to be associated with being the woman of the house. I'm working on it, but she does a lot of the thinking through the things and the jobs that need doing around the house. So tracking data would have been a bit much for her. So now we've kind of split it - I'm doing the gas and I'm doing the tracking of electricity and all that sort of stuff. And she's doing the food waste weighing. So when I've had the shower, I go and look at the gas and then I'm sitting down. Then she cooks and scrapes*

the plates before they go into the dishwasher and weighs the food waste. I think that's how we're splitting it and that's how we're kind of engaging with it".

Barriers of Engagement with Sustainable Practices: Lack of Responsibility and Motivation. We came across household H8 who expressed skepticism about their individual impact on the environment, noting that wealthier individuals and organizations could contribute significantly more by making small adjustments. This perception diminished their sense of responsibility or motivation to engage in environmentally friendly behaviour: *"Personally, in my situation, my financial difficulties, time constraints, and everything else, I don't think anyone should mention that to me. Hearing about the number of trees that I have saved is the last thing I think of. Why target me? Because I'd say these millionaires in the world are using tons of electricity, they can easily save 100 times more than what I save just by turning half of their lights off. That's what I think about when I think about environmental awareness. I don't think I'm a good target for environmental awareness. I am aware of it. I'd say 'you're targeting me to save the environment? Just turn the building lights off'. That'll save much more."*

Visualisations Mediating the Transparency on Energy Usage in Shared Living Spaces. We came across household H7, which mentioned that visualising household consumption could benefit the transparency in shared living spaces. The male participant in H7 recalled an incident from the past where he lived with a colleague in a shared house while working on a previous job in another country several years ago. Despite using their own air conditioners in each room, they shared the electricity bill equally and agreed to be mindful of their usage. They were receiving high electricity bills. He thought his AC was consuming more power as it was loud and, therefore, tried to use it less. However, the high electricity bills persisted, and he began to feel that his colleague might be using the AC more: *"I couldn't shake the feeling that my roommate was using his AC more than me, but there was no way to prove it without awkwardly going into his room to check, which wasn't an option.* This growing suspicion then led to *"a tension between us, and by the time our tenancy ended, we were no longer on good terms. The frustration of not knowing who was using more electricity stayed with me, and from that point on, whenever I searched for a new place to live, I insisted on having separate electricity meters to avoid any future disputes".* He reflected on this past experience and compared it with Eco-Garden to explain how a data visualisation can mediate transparency and avoid disruptions in relationships: *"Reflecting on that experience, I think a system like your device, with clear visual feedback (...), could have saved us from all that frustration. If we had been able to see exactly how much power each AC was using, it would have brought transparency and accountability, avoiding unnecessary conflict. In any shared living situation, this kind of device could really help keep the peace, making sure everyone is responsible for their own usage without any guessing games".*

5.3.6   Limitations and Suggestions for Improvement of the App.
Household H6 expressed a desire to rename the household appliance names on the app to their liking or assign an animal to each device: *"I would like for the app actually to be able to change the names of different items. Or maybe have an animal for each like a rat for food waste".* Further, Household H14 mentioned that the manual entry to the mobile app was forgetful at times: *"I need to remember that I need to enter my data. I think one day I forgot to enter the food consumption, but in future, if things are automatic then that might be easy".* Aligned with this, household (H9) also mentioned that it would be convenient to have a way to measure food waste automatically instead of having to enter it through the mobile app: *"if our food bin just had something that every time you dump something in it, it came up on the app saying did you dumped this amount of food in there, it would be easy".* Household H14 mentioned that the textboxes, one to input the weekly goal and the other to input gas or food waste data are too close and could lead to mistakes: *"you know the the box for entering the weekly goal and the consumption? They're very close. Sometimes I enter the goal in the place for consumption. So maybe just redesigning or relocating*

things and the page would help." They further mentioned that the manual entry of gas and food waste data can be forgetful at times.

We came across households H5, H8, and H9 who expressed a disinterest in sustainability tips and the quote on 'trees saved' features on the app. H8 said their current life circumstances left them feeling too overwhelmed and time-constrained to engage with environment-related tips/messaging. The sustainability-focused communications did not resonate as intended for individuals in similar situations and was counterproductive. Their primary motivation is not environmental consciousness but rather focusing on personal issues, such as finances and work, while managing consumption within set targets: *"I haven't been reading the sustainability tips and the number of trees saved. To be honest, at my stage and my age, and my circumstance, I'm really busy, really tired. Hearing about the number of trees that I have saved is the last thing I think of. Personally, in my situation, my financial difficulties, time constraints, and everything else, I don't think anyone should mention that to me. (...) My target is not to meet the target and see if I can still reduce the temperature without feeling really uncomfortable with it and it's actually working. Unintentionally It's working, so it's good".* Further, H9 mentioned that their main aim of the app was to look at the consumption and therefore, they do not look at the sustainability tips: *"I didn't notice them that much and because the main reason I was going into the app was to go and log something or to check how one of our devices were getting on. So I very quickly scroll past the sustainability stuff to get into the menus".* Household H8 stated that they would only want to set the goals and see the consumption charts in the app, hence did not need to have any other functionalities such as how much Carbon Dioxide they reduced due to their daily consumption curtailment. They were not interested in seeing carbon emission and rather preferred it moved away from the main screen: *"I'd rather see the charts in my home screen, and the general information. I know I'm saving electricity. I'm saving CO2 or whatever. But that's not the main goal for me using the app. That's not my main point of opening the app. I want to visualise my data. So I'd like to have that on my home screen and then have a little section on another page to show how much CO2 I have saved or how much it affects the world. I care about myself more. A bit selfish."*

Household H9 mentioned that although the app shows which device consumed the most electricity on a given day, understanding which device consumed the most electricity in a given hour is somewhat difficult in the app: *"I'm looking at the peaks and troughs in our usage in terms of the hours per day and found that it is difficult to understand and make an awful lot of sense of. I can see we have the coffee machine and the kettle on yesterday and how much they've used individually. But given one hour in the morning, I can't see which one uses the most electricity. I think the kettle was on three times. The Coffee Machine was probably on only once or for the dispensing mode, and then it was on heat-up mode a couple of times. So yeah, the daily electricity consumption may not be so much for the coffee machine."* They further mentioned that it would have been convenient if the food wastage monitoring was automated: *"if our food bin just had something that gives the weight every time you dump something in it, and it comes up on the app saying did you dump this amount of food in there. That would be easy".* They further faced an issue with measuring food waste in week 3 as they put the recyclable sponges in the same food bin and were not aware if that should be measured and entered into the app. They further mentioned if there was an ability to add the data for the previous day into the app then that would be helpful. Additionally, household H9 also explained how they found workarounds towards appropriation of the Eco-Garden to their home by creative accounting where they *"felt like cheating and entering the food waste data to Monday so that we won't go past the goal this week. The system resets on Sunday night. So we kept the food reading with us and entered it on Monday. I'm not proud about it. So I'm like when I'm getting close to a target in a given week, do I just wait until tomorrow to log it? Same for gas. We put the heating on before we have a bath. Then I think about whether to enter it that day or not".* This led to them not reporting the exact daily food waste on the app.

6 Discussion

The findings from this study demonstrate the potential of eco-feedback systems, such as the Eco-Garden mobile app, to foster sustainable practices in households. We noticed from the results of our survey on climate attitudes and curtailment actions that the respondents' attitudes and consumption reduction actions displayed a favourable change from the beginning of the study to the end of the study. Further, the Eco-Garden mobile app was generally perceived as easy to use and straightforward, provide understanding of consumption and taking action to reduce it, while the majority of our participants mentioned a preference for long-term use. Looking at the quantitative data log of household consumption, we see that most households have attempted to reduce their electricity and gas usage, and food waste in general. Looking at the goals set by households (Table 2), we can see that participants have attempted to reduce their weekly targets or maintain them at the same level. There are certain visible spikes in consumption for certain households, for example, we notice household H2 had high electricity consumption in week 1 which was attributed to their electric heating fan. They were unaware that the heating fan was using a large amount of power. We also notice that certain Nuclear Family households (H10, H11, H12) have higher food waste, and H10 has higher gas consumption. Further aligning with our qualitative findings, most participants mentioned that in addition to gas heating, appliances that use electricity to generate heat, such as electric heaters and kettles, consume most power. Our findings align with Kavousian et al. [41] where they state that the number of occupants and high-consumption appliances such as electric water heaters are the most significant determinants of daily maximum consumption of a home. In our study, we also noticed that some households set weekly goals that were way above their consumption as they were unaware of their weekly consumption. While high gas consumption in H4 and H10 could be because they have children as previously reported [11, 31], H8 had its bills included in the rental payment and had high gas consumption even though it was a single-occupant home.

6.1 The Role of Goal-Setting, Feedback, and Self-Motivation in Fostering Consumption Reduction

Goals and motivation play a critical role in encouraging people to engage in more sustainable action. Literature has demonstrated the motivating power of goals even when they are non-binding (there are no explicit material rewards tied to achieving or failing the goal) [2, 45, 46]. Our findings show how participants developed many strategies to reduce consumption in order to stay below the weekly target, without receiving incentives/rewards for sustainable actions. In fact, it has been found that when confronted with a goal, people naturally use the information and abilities they have already learnt that are relevant to achieving the goals [44]. People will intentionally prepare to develop methods or strategies that will allow them to achieve their goals if the task for which a goal is given is unfamiliar to them [73].Aligning with these, we found participants were using the facts gathered from external knowledge sources and their previous experiences to attempt to shift, better manage, and reduce consumption at home.

Our findings align with theories of goal-setting where clear, specific, and attainable goals [45, 46] enhance motivation [4] by giving participants an aim to work towards. Self-Determination Theory [45, 46] makes a distinction between what individuals try to achieve (i.e., their goal) and why they participate in a behaviour (i.e., their motivation). This theory views motivation as a more complex construct than mere self-interest, therefore, it can aid in establishing a clear separation between motivation and goals. Baxter and Pelletier [4] stated that "a goal can be considered the desired or valued outcome to be derived from, or achieved by a particular behaviour or series of behaviours, while motivation can be considered the experiential, cognitive and emotional reason(s) why a person would desire that outcome, and the force of energy necessary to enact the behaviour".

According to Locke and Latham [45, 46], there are four ways in which goals affect performance: 1) Goals have a directing role; they focus attention on actions that are related to the goal and remove those that are not, 2) goals serve as an energising factor, and this effect is shown in both conduct and cognition; high goals lead to greater

effort than low goals, 3) goals affect persistence when participants are given control over the amount of time they spend on a task; and 4) goals influence action indirectly by causing the arousal, discovery, and/or application of knowledge and strategies relevant to the task at hand. Further, Locke and Latham [46] stated that feedback is one of the moderators of goal performance. People prefer clear feedback that shows progress towards their goals in order for them to be productive; as it is difficult for them to change their actions to meet the goals if they are unaware of how they are performing. Our findings complement this previous work as the visual feedback provided by Eco-Garden's mobile app help them to gaininsights into whether participants were not exceeding their target consumption levels. Direct feedback helped participants adjust their actions to shift practices and reduce their consumption further. In the context of Eco-Garden, households could see the result of their efforts on the mobile app (and also the data sculpture), which not only reinforced their commitment but also provided a sense of satisfaction when targets were met [46]. The households' engagement with the app to record gas and food waste data and also set goals, reflects how self-motivation [4] is increased when participants are given continuous feedback in their consumption-reduction journey; rather than passively receiving information, households were encouraged to actively explore and understand their consumption patterns through the mobile app. When users actively participate in tracking their own data, they are more likely to internalise the environmental impact of their actions [4], leading to changes in their actions. For example, household H10, once users internalise the process of tracking and reducing consumption, the practices may also become habitual leading to prolonged sustainable actions. Household H6, for example, highlighted how the process of manually self-reporting food waste heightened their awareness. The incremental achievement of these goals created satisfaction [46] motivating them to set more ambitious targets.

Nonetheless, 34% of participants found the 'number of trees saved' metric unhelpful, and 27% did not find sustainability tips motivating. The 'trees saved' metric was intended to translate abstract consumption reductions into tangible environmental impact. However, such equivalency representations may oversimplify complex ecological processes and risk reinforcing a narrow, quantifiable framing of sustainability. As critiques within Sustainable HCI have argued [12], eco-feedback systems often reduce environmental responsibility to optimisable numerical indicators, potentially obscuring the broader social and material contexts of everyday practices. For some participants, the abstraction of converting kilowatt-hours into 'trees saved' may have felt disconnected from their lived routines, thereby limiting its motivational value. Rather than deepening reflection on the practices that produce consumption—such as cooking, heating, or food storage—such metrics may unintentionally shift attention toward performance indicators. Similarly, the sustainability tips feature was designed to scaffold behavioural change through actionable suggestions. However, mixed responses indicate that prescriptive guidance may not always align with households' contextual realities. Participants who were already highly motivated or knowledgeable may have perceived tips as redundant, while others may have found them insufficiently tailored to their constraints. These findings suggest the need for more context-sensitive, practice-oriented forms of feedback that situate advice within households' material conditions and routines rather than relying on generalised recommendations. Future iterations of Eco-Garden could explore participatory or adaptive tip generation, grounded in observed practices rather than static guidance.

While individual goal-setting and self-motivation play an important role in encouraging sustainable practices at home, it is equally important to acknowledge the broader systemic and structural dimensions of sustainability [8]. Household behaviour change alone can only go so far without supportive infrastructures, policies, and community-level initiatives that make sustainable choices more accessible, affordable, and convenient. By recognising the interplay between personal responsibility and systemic support, interventions can be designed not only to empower individuals but also to align with wider social and policy frameworks that enable lasting and scalable change.

While Eco-Garden currently incorporates goal-setting and reduction tracking, which may appear aligned with efficiency-oriented optimisation ('lower is better'), our intention was not to frame sustainability as an

endless pursuit of minimisation. Rather, the system aims to make consumption visible so that households can define what constitutes 'enough' within their own circumstances. However, we acknowledge that the current interface—particularly its progress indicators and reduction framing—implicitly privileges downward trends and may unintentionally reinforce an efficiency logic over a sufficiency logic. Sufficiency differs from efficiency in that it centres the question of appropriate levels of consumption rather than continuous improvement. Although participants were invited to set their own goals, the system did not explicitly prompt reflection on whether further reduction was desirable, feasible, or socially just. In this sense, Eco-Garden currently operationalises sufficiency only partially—through self-defined goals—rather than through explicit threshold-setting or reflective questioning around 'acceptable' levels of use. Future iterations of Eco-Garden could consider more explicitly support sufficiency by allowing households to define stable consumption bands rather than reduction targets, prompting reflection on needs versus wants, encouraging collective discussion about sufficient consumption at home.

An important insight from our findings concerns the heterogeneity of baseline consumption levels across households. For example, households such as H6 and H3 set reduction goals that were close to, or in some cases below, their existing consumption levels. This may indicate that these households were already operating at relatively high levels of efficiency, or that they perceived limited scope for further reductions due to infrastructural constraints (e.g., housing insulation, appliance efficiency, rental restrictions), or established routines shaped by other responsibilities. In such cases, reduced goal ambition should not necessarily be interpreted as low motivation, but rather as an indication of structural ceilings on optimisation. These observations highlight a limitation of one-size-fits-all, reduction-oriented eco-feedback systems. When 'lower is better' becomes the implicit norm, households with already modest consumption may experience diminishing returns, frustration, or disengagement. Designing exclusively around downward optimisation risks overlooking the needs of households whose sustainability challenge is not further reduction but maintaining already low-impact practices under changing life circumstances. Future interventions could therefore incorporate adaptive feedback mechanisms that account for baseline efficiency, shifting from reduction framing toward maintenance, stabilisation, or sufficiency-oriented reflection where appropriate. Rather than universally encouraging further minimisation, eco-feedback technologies might support households in identifying sustainable thresholds, preserving effective routines, and recognising contextual limits. This suggests the need for differentiated design pathways that respond to household diversity, moving beyond uniform goal-based optimisation toward more context-sensitive and equity-aware sustainability design.

6.2 Bridging the Gender Divide in Household Sustainability: From Traditional Gender Roles to Promoting Shared Responsibilities

Our findings from household H9 suggest how traditional gender roles view the wife initially as responsible for the management of electrical appliances and food waste. This aligns with the literature on male gender role and the lack of responsibility with involvement in household chores by men as it is higher in women [14, 29, 54, 66]. The majority of household chores and childcare continue to be done by women, despite men's increased commitment to these responsibilities [66], and women have historically been primarily in charge of scheduling family activities [20, 53]. Additionally, the wife of H9, thinking of data entry as burdensome, highlights a common disparity in how men and women perceive and engage with household responsibilities. This may suggest that women who are already managing a significant share of the household tasks, see added responsibilities (such as tracking data) as another layer of work rather than a tool for change. It is stated that women do two to three times as much housework as males [17]. According to these general trends, men and women have distinct sociotemporal expectations, which means that men continue to prioritise their jobs while women continue to prioritise their families [20]. Although household H9 initially viewed the wife as responsible for household activities, they later

demonstrated a shift towards a more collaborative approach where the husband recognised the unequal burden on his wife and took steps to share responsibility by tracking gas and electricity usage while she focuses on reporting food waste. This division of labour [48] allows both partners to engage with their household consumption management while easing the wife's house work. This aligns with research showing that men are increasingly attempting to engage more actively in household duties, particularly as awareness of gender imbalances in domestic labour grows [48, 66]. This difference in how men and women approach household activities illustrates the challenge of adding extra consumption-monitoring tasks in already overloaded households, particularly where gendered expectations persist.

It is important to note that while one household described women as taking greater responsibility for food planning and energy management, our study was not designed to systematically compare engagement across genders. We did not conduct structured disaggregation of interaction frequency, goal-setting behaviour, or reported change by gender. Therefore, our observations should be interpreted as indicative rather than suggestive. The findings suggest the possibility that sustainability technologies intersect with existing gendered divisions of labour, but further research with explicit gender-sensitive design and analysis would be required to substantiate this claim.

6.3 Balancing Comfort and Resource Saving Practices through Small Changes

We found that several households followed different strategies to manage household consumption. For example, our findings from household H8 illustrate how reducing electricity consumption by turning their heater on and off more frequently, rather than leaving it on continuously, can lower the consumption without sacrificing comfort. Similarly, H10 started to heat up the food for the entire family in one go, while H6 was mindful of leaving the rice cooker in a 'warm' setting for too long. This aligns with previous studies, which emphasize that resource savings are most effective when the inhabitants' comfort is considered [40, 70]. It is argued that comfort should be understood not as simply a physical state but as a social construct intertwined with energy-intensive practices [24]. As Shove argues, "in determining what people 'need', the science of comfort has allowed designers to produce buildings and systems that meet and at the same time create [narrow] expectations of comfort" [72]. Our findings highlight that small adjustments in practices, such as changing the timing and frequency of appliance use, can reduce resource consumption without decreasing comfort. This insight challenges the narrow expectations of comfort and suggests that resource savings can be achieved through thoughtful, everyday practices, rather than solely relying on technology.

The requirement for participants to manually enter gas consumption figures and estimate food waste quantities introduces several methodological considerations. First, manual reporting carries the risk of measurement error. While participants were provided with general guidance on how to read gas meters and weigh food waste amounts on the weighing scale, some entries data may include mistakes caused by manual reporting. The consumption data should therefore be interpreted as indicative and relational (i.e., useful for prompting reflection and comparison over time) rather than as exact or scientifically precise measures of household resource use. Second, the act of routinely logging data may itself have influenced participants' awareness and behaviour. Repeated exposure to consumption numbers and the effort involved in entering them may have heightened salience, functioning as an intervention independent of the visualisation component. This observation effect-sometimes referred to as measurement reactivity-complicates attribution of reported changes solely to the Eco-Garden interface. Engagement and reported behavioural adjustments likely emerged from a combined effect of data entry, visual feedback, and ongoing researcher contact. While this increased attentiveness aligns with the study's aim of fostering reflection on everyday practices, it limits claims about the isolated impact of the visualisation design and should be considered when interpreting the findings.

6.4 Motivation and Household Accountability in Designing Eco-Feedback Systems for Everyday Life

Wenshun et al. [80] argue that a strong sense of environmental responsibility is directly linked to an increased intention to engage in energy-saving actions. Further, Long et al. [47] found that the perception of environmental risk plays a significant role in shaping emotional responses, which in turn can influence environmentally friendly behaviour. Strengers [75] explored the challenges of designing eco-feedback systems that integrate into everyday routines, addressing daily practices and non-negotiable activities [3] that shape household consumption, so that the systems can help users make better consumption management decisions [60, 75]. We found that certain households in our study explored ways to shift practices and reduce consumption even beyond the Eco-Garden system by researching resource-saving modes on appliances and becoming more conscious of their broader consumption of food and electricity. Participants planned for future consumption while also thinking of home retrofitting. Some households (H10) found practical ways to reduce consumption, such as combining meal and drink preparation for the whole family to minimise microwave and kettle use. This suggests that Eco-Garden encouraged reflection on overall household consumption.

Karjalainen [39] analysed different ways of presenting feedback on electricity consumption and found that users have preferences for different forms of feedback, including graphical displays, user-friendly data visualisations, presentations of costs (over a period of time), appliance-specific breakdown (information on what proportion is consumed by each appliance), and historical comparison (comparison with their own prior consumption). Aligning with [39], we found that several households, such as H4, H10, and H15, found the Eco-Garden mobile app easy to use and helpful in tracking their electricity, gas and food waste. The app's simplicity, clear data visualisation for electricity, gas and food waste, and focus on the electricity consumption of each appliance encouraged continuous use, helping participants monitor progress and change activities [39, 61]. Participants mentioned that compared to the more complex and less intuitive charts provided by energy suppliers, the Eco-Garden app offered a more user-friendly interface that helped them clearly identify how much electricity was consumed by each appliance [56, 60]. The visual appeal and straightforward design of the app also encouraged frequent use where households reported checking the app multiple times per day and found it motivating to see how their small changes in activities influenced overall household consumption [59, 61, 62].

It is argued that social networks and peer feedback have the potential to motivate individuals to engage in sustainable practices, particularly in reducing energy consumption [49]. Further, household members have the capability to hold each other accountable for their consumption leading to practising sustainable actions [60]. Aligning with these, we found that family involvement played an important role in holding people accountable for their consumption habits, as shown in household H7 where feedback from family members helped uncover areas for improvement, encouraging self-awareness and leading to more responsible consumption practices.

Aligned with Gamberini et al. [33], we found that the engagement with the mobile app gradually reduced over the three week period, however, participants used the app when they wanted to get to know their consumption. Our participants explained that by week three, having learnt what the mobile app has to offer, they did not have a need to engage with the app regularly [33].

6.5 Reflections on the Study, Future Directions, and Limitations

Our findings suggest how household sustainability practices are often entangled with existing divisions of domestic labour, which are frequently gendered. This raises questions about whether interventions such as Eco-Garden risk reinforcing these imbalances by placing additional responsibility on those already carrying a disproportionate share of household work. We take the stance that sustainability interventions must be attentive to the gendered dimensions of domestic labour. While our findings illustrate that tools such as Eco-Garden could inadvertently reinforce existing imbalances if not carefully designed, our intent is to use visibility and shared interaction to encourage more equitable participation among household members. Rather than adding to

the hidden labour often carried by women, we envision Eco-Garden as a way of redistributing responsibility and supporting sustainability as a collective household practice. We acknowledge this as an ongoing design challenge, and future work should explicitly address equity to ensure that sustainability-oriented technologies do not reproduce or exacerbate social inequalities.

In addition to efficiency-oriented strategies, the concept of sufficiency offers a valuable complementary design principle for sustainability [1, 8]. Whereas efficiency focuses on optimising resource use, sufficiency emphasises the notion of "enough" and the need for absolute reductions in consumption. Integrating sufficiency into systems such as Eco-Garden could enable households to reflect on and define their own thresholds of acceptable or "sufficient" consumption, rather than continuously striving for incremental optimisation. Such an approach not only deepens the theoretical contribution of this work but also gestures toward design opportunities that foreground restraint, self-defined limits, and collective responsibility as central elements of sustainable living.

Another point to acknowledge is the potential for rebound effects, where resource savings achieved in one domain may be offset by increased consumption elsewhere [18] (e.g., savings from reduced energy use being redirected into additional purchases or activities with their own environmental impact; using money saved on lower electricity bills to buy more electronic devices). Although participants in our study did not explicitly mention redirecting savings in this way, the literature highlights that such effects are common and can complicate the overall impact of household sustainability interventions. Recognising this possibility underscores the importance of designing systems like Eco-Garden not only to support reductions in specific practices but also to cultivate broader sufficiency-oriented mindsets that discourage compensatory increases in other forms of consumption (see [8, 67]).

Although Eco-Garden focuses on household practices, some participants indirectly referenced structural constraints shaping their consumption. For example, some noted limitations imposed by housing insulation quality, appliance efficiency, or rental conditions. However, explicit discussions of grid decarbonisation, national energy policy, or infrastructure reform were largely absent from participant reflections. This absence may indicate that the intervention, despite its theoretical grounding in practice theory and systemic critique, operates primarily at the level of individual and household responsibility. In this sense, Eco-Garden risks reinforcing the individualisation of sustainability, a concern raised within Sustainable HCI literature. At the same time, participants' reflections on limitations suggest awareness that change occurs within infrastructural limits. This highlights an important design tension: while household-facing systems can enable reflection and coordination of practices, they cannot substitute for structural transformation. Eco-Garden should therefore be understood as complementary to - rather than a replacement for - policy, infrastructure, and market reforms.

It is stated that eco-feedback systems have achieved consumption reductions predominantly within the range of 5–15 per cent [21, 75]. However, eco-feedback is likely to be appealing for mostly environmentally motivated people, and conservation benefits may wane over time [37, 55, 75]. Therefore, future research may focus on exploring the prolonged engagement with eco-feedback systems to uncover what design strategies could aid in sustained engagement with such systems in the long term. Further, some households (H5, H8, and H9) were less interested in the sustainability tips offered by the system. This insight suggests that sustainability tips/messages can sometimes be counterproductive if they do not align with the immediate priorities of individuals, highlighting the importance of tailoring environmental messaging to the context of the user [33].

In our study, we used TP-Link Tapo P110 smart plugs to measure the electricity consumption of the households. We requested our participants to select up to 10 appliances that they use the most during the day, and we set up smart plugs for those devices. Therefore, we do not measure the electricity consumption of the entire household. The purpose of our study was to display the disaggregated electricity consumption for the most common household activities such as cooking, doing laundry, entertainment, or washing so that it resonates more clearly with participants. Future research may benefit from monitoring the whole-household electricity

consumption or connecting with the household meter and coming up with a method to collect the data in a disaggregated way.

We noticed that the women who took part in our earlier workshops (phases 2 and 3 of the research [62]) remained silent while talking about technology-related topics (such as the existing screen-based application of their energy suppliers). This was mostly due to the fact that the men who took part had access to the mobile applications, whilst the other members did not [62]. As a result, when the participants were asked to compare their daily power usage, the men took the lead. However, we saw that the women were actively participating in the consumption-related conversations in the present field study (phase 4 of the research), displaying the data on the app and describing how their daily activities related to consumption. Additionally, some households thought this study may share their use data with energy suppliers, which at first caused participants to give careful responses. Questions about the data's visibility and confidentiality of household consumption were also brought up by participants. The researchers explained the Eco-Garden system to familiarise them with the data collection and maintenance process, which then facilitated open discussions.

Our three-week deployment provides insight into early-stage engagement but limits claims about sustained behaviour change. The decline in engagement observed in some households (e.g., reduced interaction by Week 3) suggests the possibility of novelty effects influencing early enthusiasm. Short-term increases in awareness do not necessarily predict long-term practice reconfiguration. Although participants reported reductions in certain domains of consumption, the study's short deployment period and reliance on self-reported behaviour limit conclusions regarding overall environmental impact. The absence of explicit references to rebound behaviour—where savings in one domain lead to increased consumption elsewhere—should not be interpreted as evidence that rebound effects did not occur. Rebound dynamics often unfold over longer timeframes and may not be consciously recognised by participants. Moreover, financial or time savings resulting from reduced energy use could potentially be redirected toward other forms of consumption not captured in the study. Given the three-week duration, the findings are best understood as indicative of short-term reflective engagement rather than confirmed systemic reduction. Recognising this limitation is particularly important given broader critiques of individual-focused sustainability interventions, which caution against overstating their aggregate impact. Given the three-week duration, the findings are best understood as indicative of short-term reflective engagement rather than confirmed systemic reduction. Recognising this limitation is particularly important given broader critiques of individual-focused sustainability interventions, which caution against overstating their aggregate impact.

While our study did not involve a large, representative sample of UK households, it is important to note that it is not uncommon for qualitative research to employ similar sample sizes (see [13, 35, 36, 51]). The participants in our study had diverse backgrounds and household sizes; however, future research could benefit from including a broader range of participants from various socioeconomic backgrounds, cultures, and perspectives. Participants were recruited primarily through university-affiliated mailing lists and social media networks. This recruitment strategy likely introduced education and socio-economic bias, as households connected to university communities may possess higher levels of environmental awareness, digital literacy, and access to resources compared to the general population. As a result, participants may have been predisposed toward sustainability engagement or more comfortable interacting with experimental technologies. The findings should therefore be interpreted within this demographic context and should not be generalised to less resource-privileged, digitally excluded, or environmentally disengaged households without further study. As we explored children's design preferences through their parents, future research may benefit from directly involving children to understand their choices and requirements for physicalisation design. Although our study was carried out for three weeks with each household (N = 15), it is not uncommon for qualitative research to be conducted for short periods (see [32, 68, 74]). However, future research may benefit from conducting a long-term study to understand the prolonged engagement of participants with eco-feedback [37, 55].

7 Conclusion

This study highlights the role that Eco-Garden, an eco-feedback system, can play in promoting sustainable household practices. By offering feedback and intuitive visualisations, Eco-Garden could empower households to make more informed decisions for shifting practices and reducing their environmental footprint. Our findings suggest that eco-feedback systems can encourage reflection and household discussions, encouraging users to reconsider their consumption habits. We found that women often carry out the majority of domestic tasks, and it is important to navigate household sustainability without sacrificing comfort. We underscore the importance of goal-setting in giving users an aim to work towards, and how self-reporting can enhance the reflection on self-consumption practices. We demonstrate the potential of eco-feedback systems to support sustainable living by integrating with household routines and practices. Our study also highlighted how self-motivation is necessary to encourage sustainable practices.

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