# Eco-Garden: Fostering Sustainable Practices through a Data Sculpture to Reduce Household Consumption

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**Abstract.** As sustainability becomes an urgent global priority, systems that support consumption reduction in households are essential. We present the design and development of Eco-Garden, a data sculpture and a companion mobile app, that visualises household consumption for electricity, gas, and food waste. Eco-Garden was developed through a four-phase, human-centered design process, incorporating insights from participants including goal-setting, peripheral interaction, aesthetics, and child-friendly features. While the sculpture delivers intuitive feedback, fostering awareness through subtle visual cues without demanding constant attention, the mobile app allows for detailed tracking and goal-setting. Positioned in shared spaces in households, the sculpture encourages sustainable practices as a whole-household effort. We report findings from a three-week field study with 15 households that suggest that the constant physical presence and feedback of Eco-Garden supported an ongoing awareness of consumption and motivated shifting practices through clear and achievable goals. This study contributes to eco-feedback research by demonstrating the impact of physical feedback in households.

**Keywords:** Data Visualisation · Data Sculptures · Peripheral Interaction · Eco-Feedback · Sustainability · Household Consumption.

## 1 Introduction

In the context of rising global climate concerns, there is an increasing emphasis on systems that encourage sustainability in everyday life in households. Among these, eco-feedback systems have gained attention, which is defined by Strengers [52] as "technology that provides feedback on individual or group behaviours with a goal of reducing environmental impact" (adapted from [29] and [40]). Eco-feedback helps individuals understand, monitor, and ultimately reduce their consumption [33,22]. While eco-feedback systems have shown promise to reduce consumption, their impact depends not just on the information it conveys, but

also on how intuitively and meaningfully this information is delivered to users [49,47]. The success of eco-feedback systems depends on the clarity of the feedback and on their ability to integrate it into the household's daily routines [45]. While screen-based eco-feedback systems can help reduce consumption, these require the user's attention and can be disruptive to daily activities [24].

In addition, Backlund et al. [2] stated that investigating how objects are designed and how people interact with them provides a different viewpoint on how the form of data representation affects perceptions and energy usage in daily life. Physical data visualisations have the ability to communicate information to people while remaining in the periphery of their attention and not disrupting the users' actions [14,56]. They can also blend into a household context and its physical presence can encourage user's engagement and interest [51,49,56].

This paper explores the role of a data sculpture, Eco-Garden, designed to represent household consumption moving beyond traditional screens and numbers, and offering a more visual and engaging experience. In this paper, we present the results of a user study with 15 households that interacted with Eco-Garden for three weeks. Aligning with prior work [51,49,56], we constructed Eco-Garden to visualise electricity, gas usage as well as food wastage. Our work contributes to the growing body of physical data visualisations in Human-Computer Interaction (HCI) research [49,11,56,43,46]. Our findings show how the constant visual feedback and physical presence of EcoGarden enhanced the understanding of consumption, goal-setting and curiosity about one's own and households' consumption, leading to shifting consumption habits, and how people relate their understanding of data to the feedback method.

Our paper has three major contributions. First, we design and evaluate a novel data sculpture that fits within household daily routines and practices, moving beyond traditional eco-feedback systems that focus on individual behaviours and abstract carbon metrics [51,49,50]. Unlike previous research designing eco-feedback [18,51,49,42], we move away from researcher-defined goals to human-centred design and user-led feedback goals. Second, we extend research on peripheral interaction [3] by exploring how unobtrusive feedback influences the understanding of household consumption, awareness, and daily habits. Third, our findings also show how replacing extrinsic incentives [41,28] with other more intrinsic engagement and motivation strategies (self-driven curiosity and goal-setting [36,37]), led to reduce consumption.

## 2 Related Work

To situate how our work builds on prior ideas and concepts around "data sculptures", we briefly present the background of data physicalization as a research area [32] and reflect on insights from related research fields.

Eco-feedback systems [29,40,52] provide users with information about their resource consumption through in-house displays (IHD) [55], web-based and mobile applications [34], games [19], thermal imaging [26], virtual environments [9], and tangible user interfaces [13], to raise consumption awareness. Research has

demonstrated that eco-feedback can lead to reductions in energy use, typically ranging from 5% to 15%, by making consumption patterns more visible and understandable to users [52,20]. One of the central concepts underlying the usefulness of eco-feedback is the continuous feedback that allows individuals to track and respond to their usage [40]. However, traditional forms of eco-feedback, such as smart meters or mobile apps, often rely on numerical data or graphs that may not be easily interpretable for users, and less engaging [3,47]. This has led to the exploration of alternative methods, such as data sculptures and physicalizations, to make consumption data more intuitive and engaging [14].

Ishii and Ullmer [31] introduced the concept of physical data representations through their work on 'tangible bits'. In 2008, Zhao and Vande Moere [56] introduced the term 'data sculpture' as "a data-based physical artefact, possessing both artistic and functional qualities, to augment a nearby audience's understanding of data insights and any socially relevant issues that underlie it". In 2015, 'data physicalization' was described by Jansen et al. [32] as "a physical artefact whose geometry or material properties encode data". Physical data visualisations can transform abstract numbers into meaningful forms, providing users with a way to experience and engage with data through sensory interaction [14], remaining in the periphery of attention [3,25]. Due to their artistic and functional qualities, data sculptures are suitable for households as they can retain their aesthetics while informing data in a more interesting manner [51,44,47,56].

Sustainability has become an important area in HCI research [12,5]. Mankoff et al. [38] divided sustainable HCI into two areas: sustainability in design, which focuses on lowering the environmental footprint of technologies, and sustainability through design, which aims to influence people's lifestyle choices towards more sustainable ones. Tscheligi and Reitberger [54] suggest that persuasive technology can encourage users to adopt environmentally friendly practices by showing the environmental effects of their actions. However, Brynjarsdottir et al. [8] argue that these approaches often rely on narrow definitions of sustainability and human behaviour, with designers deciding what counts as "sustainable behaviour". This prescriptive approach can limit the effectiveness of such systems and make sustainability goals harder to achieve [8]. Rather than seeking to change individuals' attitudes and actions [48], recent studies highlight that sustainability challenges are deeply rooted in sociocultural practices [16,48,10]. Everyday practices such as cooking, cleaning, and laundry, consume resources and are shaped by complex social, cultural, and material factors [16]. Targeting isolated behaviours offers a limited perspective, as fostering sustainable practices depends on understanding the interconnected systems that sustain them [16].

## 3 Eco-Garden: Design for Consumption Reduction and Promoting Sustainable Actions

In October 2021, we started a project to investigate how physical visualisations may be designed to encourage sustainable practices in UK households. Taking an iterative, four-phased human-centered design approach, we designed and devel-

oped the Eco-Garden system, which is a combination of a physical data sculpture and a companion mobile application, to visualise household consumption data in a way that encourages sustained engagement and motivates practice change. Aligning with Brynjarsdottir et al. [8], we aimed to design for sustainability by developing a system which is less about prescribing behaviour and more into encouraging people to think of their consumption in terms of daily activities. In this way, it "may encourage users to reflect on what it actually means to be sustainable in a way that makes sense in the context of their own lives" [52].

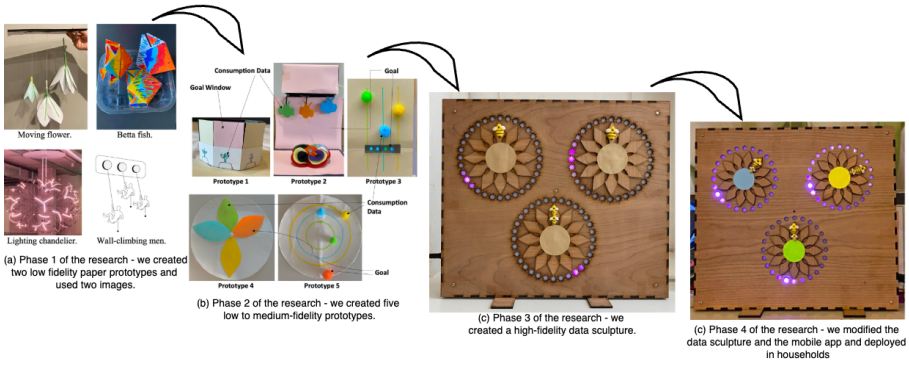


**Fig. 1.** Evolution of the design of Eco-Garden through four phases of research: (a) Low-fidelity prototypes used in Phase 1 - 'moving flowers' include a set of 3 flowers that bloom and hang from the ceiling, 'lighting chandelier' [53] is an image that represents visualising a static installation with LED strips (Reaction Diffusion (2022), Jason Bruges Studio. Image credit: Josh Partee), 'Betta fish' prototype to depict changes in colour according to level of consumption, and a 'wall-climbing men' representation that shows objects moving to reach parallel targets, (b) Low to medium-fidelity prototypes created in Phase 2 , (c) first version of Eco-Garden designed in Phase 3, and d) modified version of Eco-Garden in Phase 4.

In Phase 1, we conducted a survey (22 responses) and 13 household interviews to understand household consumption practices, curtailment challenges, and visualization preferences using low-fidelity prototypes ((a) Phase 1 in Figure 1). In this phase, we identified design considerations such as interpretability, social and historical frame of reference, goal setting, aesthetics, shared location, peripheral interaction, reward, alerts and notifications, positive reinforcement. Participants also suggested having an abstract visualisation that displays consumption data with no numbers or text (preferably a physical object), and potentially a separate mobile app that provides a detailed view [45,42,44,46]. In Phase 2, we conducted design workshops in 15 households to explore the design space for a physical artefact to visualise household consumption. We created five low to medium-fidelity prototypes ((b) Phase 2 in Figure 1) based on the design considerations identified in Phase 1. During these workshops, participants identified electricity,

gas, and food waste as the most important consumptions in their households. Participants also ranked the design considerations according to their importance. We identified key design implications as interpretability, historical frame of reference, goal setting, aesthetics, the sculpture's features including size and design for a shared location at the household, calm and comforting design, the need to make the sculpture abstract, and the potential for a child-friendly design [44].

Based on the lessons learned and key considerations from Phase 1 and Phase 2, in Phase 3 we created the first version of Eco-Garden as an aesthetically pleasing object that communicates consumption information in a friendly manner. We also designed an initial version of the companion mobile app that can be used to enter the weekly target and usage for gas and food waste, and visualise consumption graphs and progress. We conducted 14 household workshops to gather early user feedback (Phase 3 in Figure 1) on the sculpture (including visibility, understandability, aesthetics) and the app (user interface, ease of use, and understandability). Based on user feedback from Phase 3, we re-designed Eco-Garden in Phase 4 (both the data sculpture and companion mobile app) [43]. We provided flexibility and adaptability on how to display data in the sculpture to each household where participants could choose which consumption is displayed on each of the three discs: 1) display electricity, gas, and food waste data simultaneously on the three discs, 2) display electricity usage data for current and past week, and a total of all weeks, 3) display electricity and gas data, or 4) display electricity and food waste data. For instance, three of our households (H1, H6, and H7) were fully electric and did not consume gas and discs were configured to show electricity data and food waste. We then conducted a field study with 15 households where each household used Eco-Garden for three weeks.

### 3.1 Design Process: The Layers of Eco-Garden

Inspired by previous physical data visualisations in the literature [49,51], Eco-Garden's design was implemented through three distinct layers, each corresponding to one or more design implications.

**Layer 1: Visual Encoding and Physical Form** The first step in supporting data visualisation and reflection is the physical data sculpture, designed to communicate consumption information through subtle, aesthetic visual cues that are adult and child-friendly. The sculpture is constructed using three sheets: 5mm cherry-veneer wooden layer with flowers, 3mm semi-transparent acrylic layer for visual integration, 5mm opaque acrylic layer housing electronics ((a) in Figure 2). There are three discs that make up the Eco-Garden, each disc visualises electricity, gas, or food waste data, which are colour-coded as blue, yellow, and green, which are individually driven by a stepper motor. The smaller flowers around each disc are connected to addressable LED strips (Phase 4 in Figure 1), which correspond to a configurable target set by users through the companion mobile app ((b) in Figure 2) that displays detailed consumption data (complete details of the design of the mobile app is out of scope of this paper and will be

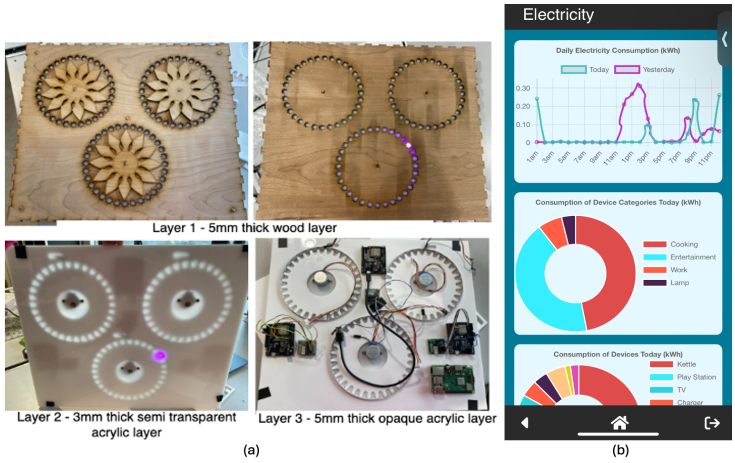


**Fig. 2.** (a) Three sheets of Eco-Garden sculpture, (b) Electricity consumption view of the companion mobile app.

reported separately). The discs follow the functioning of a traditional wall clock. Initially, Eco-Garden starts with the beginning petal with the bee pointing at the 12 o'clock position (representing a consumption of 0). The bees gradually rotate throughout the week to show consumption, while one lit LED in each disk shows the customised goal. The bees are updated every hour. After one week, the Eco-Garden resets itself (and the user sets a target for the new week) and continues the process with new data for the next week. In addition, we provide the option to adapt Eco-Garden to align with user preferences by: (1) choosing which consumption practice is visible on which disc and in which way, and (2) selecting the colour of the goal LED.

**Layer 2: Household Reflections through Self-reporting** Eco-Garden enables users to self-report and view their own consumption data on a companion mobile app ((b) in Figure 2). Eco-Garden data sculpture offers opportunities to support reflection of consumption data through rotating discs (for electricity, gas, and food waste). The discs present household consumption data, prompting users to think of ways to prevent physical bees from rotating too much and become more sustainable at the household. This layer prioritizes interpretability and disaggregated information provision by allowing households to record gas and food waste, while automatically tracking electricity via TP-Link Tapo P110 smart plugs. The companion mobile app ((b) in Figure 2) provides a simple interface with separate views for each type of data (electricity, gas, and food waste). Users can 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. Similarly, users enter food waste on the mobile app while ticking which category of food went to waste that day

(dairy products, bakery goods, fruit, vegetables, and fish/meat). Aligned with Karjalainen [33], we display daily and weekly consumption data for electricity, gas, and food waste through line and bar charts in the companion app. We 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, fruits, vegetables, and fish/meat. We also added a section on the app's home page that leads to a separate view to read sustainability tips to curtail electricity use, gas use, and food waste. We also added quotes on the home page about the 'number of trees saved' by each household based on the amount of carbon emission reduced due to their household consumption curtailment.

**Layer 3: Goal-Setting** Goal-setting is an independent yet integrated layer embedded in both the app and physical sculpture. Aligning with Locke and Latham [36,37], we allowed for weekly goal setting in the mobile app. We also added a progress bar for each page so that the user's progress is visible against their weekly goal. The data sculpture complements this process by providing an ambient, visual form of goal tracking. Each consumption category, electricity, gas, and food waste, is represented by a rotating disc that subtly reflects consumption changes, allowing users to gauge their progress at a glance. This seamless blend of physical and digital feedback provides users with a sense of where they stand regarding their goals supporting ongoing awareness of consumption.

## 4 Evaluation

In this paper, we report the results of the in-the-wild evaluation of Eco-Garden related to the data sculpture from Phase 4. We present household perspectives on data sculpture, its acceptability and its potential to encourage sustainable practices in households. We deployed the Eco-Garden in 15 households in the UK that used it for three weeks. Before the start of the study, participants were requested to read the Participation Information Sheet and sign a consent form. The field study was held between February to July 2024, with a favourable ethical opinion obtained from the ethics committee of the School of Computer Science and Informatics, Cardiff University (ref: COMSC/Ethics/2024/001). Each household received a £25 voucher.

### 4.1 Participants

During phase 1, we used our university social media group and mailing lists for participant recruitment. We invited these participants to the current study in phase 4. Here, 10 households (H1 to H10) with adults ranging in age from 18 to 54 years old, participated in the field study (Table 1). We recruited five additional households through the university network due to attrition of previous participants. Overall, household participants had one to four people per household, including five single-occupant households, four shared households between partners or tenants, and six family households with children. Although we did

not directly involve children, we learned about children's experiences through their parents. Three of our households (H1, H2, H6) were fully electric houses.

**Table 1.** Participant demographics 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)

### 4.2 Procedure

At the start of the field study, we sent out emails to participants asking them to select a time that would work best to visit each household and set up the system. During this first visit to their households, we gave the participants an explanation of the goals of the study. Each household was then given 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 house. To collect data on the electricity consumption of the appliances, we installed the TP-Link Tapo P110 smart plugs. The participants entered data on their gas usage and food waste using the mobile app. After that, we asked every household to complete a survey and participate in a 15-minute pre-study interview to learn more about their views towards climate change and their initial impressions of Eco-Garden. The survey had three parts: one was to capture participants' climate-related attitudes, second was to understand the curtailment actions taken at the household, and the third was to understand participants' first impressions of Eco-Garden. The aim of the pre-study interview with each household was to further explore participants' initial impressions of Eco-Garden in more detail. At this time, households were also requested to use the mobile app to set consumption goals for the week, which would also be displayed in the data sculpture.

We visited each household once a week and conducted a 30-minute weekly interview, in order to gather feedback on participants' experiences with Eco-Garden, how they interacted with the system, whether or not everyone in the household used it, whether or not the system encouraged any changes to routines or practices, and opinions regarding the data presentation in the sculpture and the app. After three weeks, we conducted a post-study using a survey and a household interview in each household. The post-study 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 two parts of the pre-study survey was to identify temporal shifts in climate-related attitudes and curtailment actions taken at the household. The second section of the post-study survey had three sub-sections (we shall continue the numbering of the sub-sections for convenience); 3) understanding households' overall experience with Eco-Garden system (data sculpture and the mobile app together), 4) separately understanding the experience with the data sculpture and how well it fitted into the home, and 5) 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 technology's usability. In this paper, we report on sub-sections 3 and 4 of the second section of the post-study survey. The results related to the mobile app evaluation and pre-study interview, and sub-sections 1, 2, and 5 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). We began the process by familiarising ourselves with the qualitative data, obtaining context and insight. Initial codes were produced to gather feedback on the prototype, critically assessing the influence of personal viewpoints on code selection [6]. We iteratively reviewed the transcripts, generated codes and sorted them eight times to aid in theme identification. Initially, we conducted independent analysis of the pre-study, weekly, and post-study interviews for every household. Understanding the overall experience with Eco-Garden during the period of the study was the aim of this analysis. Second, we analysed each interview set with every household independently. This was done to discover how each household's use and engagement with Eco-Garden changed throughout the course of the study. Third, we analysed the data for each week for all households separately. Understanding the system's temporality throughout each week for each household was the aim of the third analysis. All of the codes were then categorised into more general, mostly descriptive themes. 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 and across all interviews for all households. Finally, the results were grouped into four major themes. In this paper, we only focus on the results of two themes; one theme related to Engagement with

the Sculpture Shaping Understanding, Attitudes, Motivation, and Practices over Time, and the other theme on User Autonomy, Constant Visual Feedback, and Physical Presence Transforming the Understanding of Consumption (the rest of the themes are reported separately).

## 5 Quantitative Findings

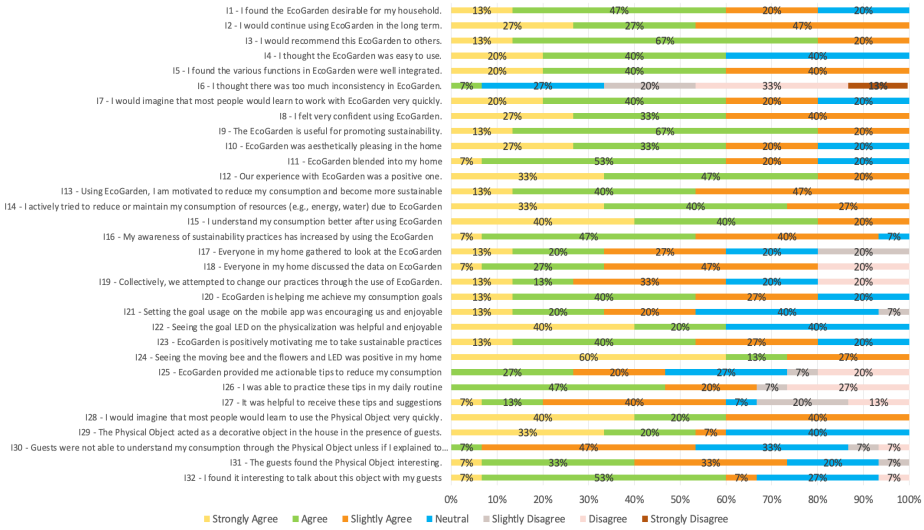


**Fig. 3.** Survey responses given via the Likert Scale with statements for the Eco-Garden system. Statement rates are shown on the rows, with the total percentages of participants responding from strongly agree to strongly disagree to the statements overlaid on the stacked bar graph.

During the survey conducted after the three-week period, we found that the majority of participants (80%) found Eco-Garden desirable for their household, while all participants agreed that they would continue using the system long-term (Figure 3). A similar number of participants (60%) thought that Eco-Garden was easy to use and that most people would learn to work with the system quickly. All respondents agreed that the Eco-Garden system promotes sustainability and they were motivated to reduce consumption at the household. More than half the respondents (60%) mentioned that everyone in the household gathered to look at Eco-Garden and discussed the consumption. Further, 60% 'agreed' or 'strongly agreed' that seeing the goal LED on the sculpture was enjoyable and useful, while all respondents said the visual encoding of bees, and the flowers with the goal LED were positive to have at the household. All participants found the sculpture desirable and useful at the household to promote sustainability. All

households preferred the design of the sculpture and the way it communicated data. 54% agreed that the sculpture was abstract to the visitors, while 67% said they were interested in talking about the sculpture with the visitors. However, 47% 'slightly disagreed' that the size of the sculpture was suitable for their household. More than half of the respondents (80%) agreed that the sculpture was easy and intuitive to understand.

We also noticed that most households showed a reduction in electricity usage. For instance, H1 reduced consumption from 1.29kWh in week 1 to 0.55kWh in week 3, while H3, H4, H7, H8, H10, H13, and H14 followed similar patterns. However, usage of H6 increased from 18.8kWh to 38.9kWh, and H2 recorded 61.4kWh in week 1 due to usage of an electric heater, later reducing consumption after recognising the high usage. H4, H8, and H10 had high gas usage initially, with 95kWh in week 1. By week 3, their consumption dropped significantly (H4: 32kWh, H8: 75kWh, H10: 57kWh). Other households (H3, H5, H10, H12, H13, H14, H15) also showed a steady reduction in gas consumption. H1, H6, and H7 recorded zero food waste throughout the study because they were motivated to reduce waste, while H10 had the highest, reaching 2.347kg in week 2.

## 6 Qualitative Findings

### 6.1 Constant Visual Feedback and Physical Presence Transforming the Understanding of Consumption

Households H2 and H6 described that being able to see their consumption through a physical device that is constantly present at the household makes them more aware of consumption than seeing it on a mobile or web app: *"it was the shock factor that got me. I think when you look at a general graph, you're so distanced from real life and I think it's the same on applications where you look at the app and you go 'oh yeah, I've used X amount of kilowatts. That line is very tall. That's a cool bar chart'. But when you look at the physical prototype and you see the bee spin in an hour, you look away and you go do whatever, and you come back and you walk past it and see that it has spun a little more, you think 'Oh my God, what have I done in the last hour that needs to stop!"* Households H1, H5 and H11 mentioned that they were able to understand their consumption with a quick look at the sculpture and compare it against the target. Similarly, household H10 mentioned that Eco-Garden was a convenient way to understand consumption: *"it's so easy. It's so understandable, it doesn't have complex things. Everything is visually very easy".*

In addition, household H4 mentioned that they were more careful with the usage of the heaters as they continuously saw the consumption on the sculpture: *"Of course I know the consumption because I see the bill at the end of the month. But I haven't thought about daily use. When I received the bill, I think 'ohh I need to reduce the consumption next month', but then I don't know how because I see the results of the consumption just once a month. So there is nothing that encouraged me to reduce the consumption. But now, when I see the consumption in front of me every day, it first reminds me, second encourages me to make*

*a change".* A single-occupant household (H6) highlighted how he placed Eco-Garden's data sculpture in his household, next to the television and close to the bedroom, to help in looking at it and interacting with it: *"I've put it in a place where I can interact with. It's right next to the television and the hoover, and whenever I'm doing chores or anything, I'm gonna be looking at it. It is next to the door to my bedroom. I'm gonna see it every time I walk into the bedroom ".*

### 6.2 Goal-Setting, Curiosity on Self-consumption Habits Leading to Reflection and Efforts to Move Toward Sustainable Practices

**Discovering and Reflecting on Self-Consumption Practices.** Household H2 highlighted that using the Eco-Garden sculpture, they became aware that their heater consumes a lot of electricity, which they did not know about before: *"when I turn on the heating fan, the bee went very, very very fast. So I was in shock. Now I know where my electricity bill comes from. I pay about 200 each month and now I know why".* Household H6 mentioned that they became more aware of their desktop consumption through the rotation of the bees: *"physically seeing the bee rotate scared me a bit because I expected it to only move one tick and it had moved like four ticks in the first day of using. It was a Sunday and obviously, I use my desktop a lot on a Sunday, so I'd seen it like jump a huge way through on that day ".*

Household H9 explained that their habit was to boil the kettle a few times due to their forgetfulness, however, they became mindful of that and attempted to prevent it from happening while using Eco-Garden: *"I realised some of the weird quirks. I double boil the kettle of water, which is a really because I'm quite scatterbrained. I kind of forget about it for 10-15 minutes and then I come back in a bit and I remember, 'Oh yeah, I was making a cup of tea' and then I boil the kettle again. Now I've been like, 'No, that's wasteful. Stay here. Get your cup of tea, and then you can go be scatterbrained elsewhere', so it's little habits like that".* H10 mentioned changes in their practices: *"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. We did these this week because we were thinking, why do we need to turn it on two times?".* Household H6 also explained that they moved away from leaving the rice cooker on the 'warm setting' for a while without switching it off: *"(...) when I was making a meal in the rice cooker, I left that on for an extra 10 to 15 minutes, which I'm used to doing. I'm sure it used up a bit more electricity than normal. I'm trying not to do it. So I've improved in saving electricity."*

**Subtlety of the Bee's Movement as a Less Overwhelming Visual Cue.** Households H4, H6, and H15 mentioned that the bee's movement in data sculpture serves as a subtle indicator of consumption offering a pleasant contrast to more direct and potentially overwhelming notifications, making it easier to engage with the feedback regularly without feeling pressured: *"I think seeing the bee move is a nice little indicator. It's a cute little way of seeing it. If it was*

*more in my face like [with a tone of high emphasis and surprise] 'you've used 15% of your power usage in the day!', I felt like that would have been too much of a shock. So just seeing the bee move like 'Oh wow, that moved a lot further than I thought'. It was a nice sort of change of pace compared to the emails that my energy supplier sends me. I'm never scared to look over at it" (H6).*

**Goal-Setting as a Challenge for Positive Consumption Practices.** Household H4 explained that having a weekly target consumption for the whole house was beneficial for everyone to visualise how much they collectively consume and try to curtail it where possible: *'it's good that that has a customisation feature that we can set our consumption target for a week. Now everyone can see what we are doing. We can all do things to reduce."* They further explained that the data sculpture was a convenient way to get to know consumption with no numbers: *"(...) it has no numbers, it has visualised the numbers in a different way. Unlike the smart meter, it really helped me to understand my consumption."* Household H15 mentioned that Eco-Garden created an enjoyable game at the household with the challenge of not exceeding the goal: *"That's not stressful. It's an enjoyable thing, and it's a positive challenge that I need to reduce. Because this will affect me positively in the end as my bill would be less. I enjoyed it".*

### 6.3 Relating Understanding to Feedback Method, Forming a Habit of Checking Usage, and the Gradual Disengagement

Household H4 explained that they could understand the electricity and gas consumption relating to the way the feedback was provided. They could 'feel' the electricity usage in terms of the visual feedback of the bee's rotation, while they could 'feel' the gas consumption in terms of the numerical values they enter into the mobile application: *"I didn't really understand the numbers for electricity, but the rotation. Well, today I didn't use the toaster or the air fryer, so I know it's not gonna move two flowers or one flower. So I can feel that consumption, not in terms of numbers but in terms of how much the bee will rotate. For gas, I understood the numbers. I can feel the numbers now. I feel the consumption more with the gas because I've entered the readings. So now I know if I put heating for one hour, how much gas will I use".* In addition, household H6 mentioned that by the first week, they had developed a routine to look at the sculpture when they walked past the living room: *"So at the end of the day, when I'm going to bed for the night, turning all the lights off and everything, I check it before I go through and just notice how far the bee has moved".* Household H5 had the sculpture in the kitchen and looked at it while cooking. Furthermore, household H9 engaged with the sculpture daily and took a picture of it and maintained a daily record of the bees' movement. Households H4, H5, and H10 mentioned that the initial excitement of the novel device at the household faded by week 3, and it became a part of the household, blending in with the other household items. However, they looked at the sculpture when they wanted to get to know the information, preserving its usefulness: *"when something is new, you're excited about it. Now we are used to it. So it's normal. I have forgotten it's at the*

*house. But we're still checking our consumption. The light and the bees attract my attention sometimes to look at the device"* (H5).

### 6.4 Suggestions for Improvement of the Data Sculpture

Household H9 mentioned that it would be helpful to be able to manually change the maximum consumption assigned to each disc for electricity, gas, and food waste themselves: *"it's such a hard thing to calibrate the maximum value at this point, but in the future having something where you can change it remotely or change it myself might be useful"*. Household H8 mentioned that if the size were a bit smaller, it would fit into some other places in other households as well: *"one thing I will change is to make it slightly smaller. For me, I have a big space in the room and I have a nice shelf and it's pretty much empty. That's not the case with many other households. Even if they have shelves, it's quite filled, but if we could make it slightly smaller, it would fit multiple places, and it's better that way, but still keep it the same design, just scale it down."* Furthermore, household H15 described that at times they counted the smaller flowers around each disc on the sculpture to remember how much the bee moved through the last hour, and suggested to have numbers next to them: *"sometimes I need to count how many flowers has the bee moved to see if it moves or not in the next hour. If the circles were numbered or something, it might be easier"*. In the same household (H15), the son unplugged the smart plug for the TV, which led the researchers to visit the household mid-week to set it up again. The parents mentioned this was something they felt scared about and would be more convenient if they were able to do the setup on their own without causing trouble: *"when my son unplugged the the the TV that day - it's the main thing that I'm afraid of - that my kids will unplug anything. Maybe if I could set up myself if that happens, that would help.* Household H10 further mentioned that it might be more convenient for their children if the discs were labelled with the names of each consumption category after they choose which disc represents which consumption practice: *"Every time my kids keep asking me which one is gas? Which one is electricity? If you could maybe add labels or something in future that might help, especially for kids. For me, I can recall by the colour"*.

## 7 Discussion

The findings from this study demonstrate the potential of Eco-Garden to foster sustainable practices in households. We noticed from the results of our post-study survey that the Eco-Garden system was helpful to promote sustainability and households preferred the visual encoding of the sculpture. Participants had favourable responses to having the Eco-Garden system in each household. Participants also reported that everyone in the house was engaged with the system and that the sculpture and the app were easy to understand.

Our work extends previous research in several ways. First, unlike studies on individual consumption behaviour that provide feedback on abstract carbon metrics [51,49] and prescribe behaviours [8], which users struggle to relate to daily

life, we adopt a practice-theory approach to examine how the socio-technical context including household routines and social dynamics, shape household consumption [16,48,35], through the support of the data sculpture. This shifts the focus from isolated decisions to the socio-technical complexities of households and the collective factors that influence household decisions regarding consumption. Second, prior physical data visualisation research [51,49] often employs a one-size-fits-all approach, leading to irrelevant or overwhelming information [51,49,17,32,15]. Our human-centred design (HCD) process explored how personalisation can be supported in practice by enabling users to determine which consumption data is most meaningful to them. Third, while Bakker's work [3] explores peripheral interaction in general contexts, our study extends this to household environments, highlighting how continuos, unobtrusive feedback influences daily consumption practices over time. Lastly, existing eco-feedback systems often struggle with declining user's engagement [41,28] due to reliance on external motivators (e.g., rewards, competition). Instead, our study shows how intrinsic motivation (e.g., self-driven curiosity, goal-setting [36,37]) can help sustain engagement without novelty-driven incentives.

In the following, we discuss how the visual feedback and the physical presence of the sculpture influenced households' understanding of their consumption data.

### 7.1 Physical Presence and Peripheral Interaction: Making Household Consumption Visible Yet Non-Intrusive

Unlike digital displays or mobile apps that require users to actively seek out information [24,45] and are prone to display and interaction blindness [30], data sculptures such as Eco-Garden remain visibly present in the background, subtly integrating into daily life [44]. This peripheral interaction ensures that users encounter the data regularly, even when they are not consciously focused on it [47]. This passive engagement with the sculpture allows for a deeper reflection and more continuous awareness of consumption patterns [56,47]. The sculpture thus acted as both a reflective and exploratory tool, allowing users to discover previously hidden consumption patterns [56]. Another important aspect of Eco-Garden highlighted by our participants was the use of subtle visual cues rather than direct or overwhelming notifications [47]. Several participants (H2, H4, H6, H15) appreciated how the gentle movement of the bee provided information without overwhelming them. Participants compared this non-intrusive feedback to the often abrupt or alarming notifications sent by energy suppliers or smart meters. By enabling users to engage at their own pace, the sculpture created a more comfortable and enjoyable interaction. This finding suggests that ambient feedback systems that incorporate subtle cues are more successful in encouraging sustainable practices [14,32,47] than those that rely on frequent and overwhelming notifications. Rather than being a device to hide away, Eco-Garden became a centrepiece that people were happy to use in the household, as described by H10. This contrasts with traditional smart meters, which are often viewed as purely utilitarian [42].

### 7.2 Encouraging Collective Action through Goal-Setting

In addition, household H4 highlighted that the game-like feature of having a shared consumption goal in Eco-Garden encouraged collective action within the household. The sculpture became a shared reference point for the entire household, enabling everyone to see how their actions contributed to overall consumption. Locke and Latham [37] stated that goal-setting can play an important role in encouraging people to take 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) [36,37,1]. By integrating goal-setting features into the sculpture, households were able to view their consumption as a challenge to be met which influenced their intrinsic motivation. This approach transforms the typically mundane task of monitoring consumption into a more engaging, game-like experience, where users are motivated to meet or stay below a weekly consumption goal [4]. For example, participants described the process as a positive, enjoyable challenge, emphasising the satisfaction of keeping their consumption below the target. Gamification is a means of supporting user engagement and enhancing positive patterns in service use, such as increasing user activity [27]. Physical feedback provided by the sculpture serves as a constant reminder of progress towards a goal, reinforcing positive environmental conduct.

### 7.3 Balancing Novelty and Long-term Engagement through Subtle Feedback and Fostering Intuitive Understanding

The Eco-Garden data sculpture helped foster continuous engagement with users by subtly integrating it into daily routines. For instance, households (H6 and H5) developed the habit of checking their consumption regularly, before bed or while performing daily activities such as cooking. Interestingly, as seen with households H4, H5, and H10, when initial novelty and excitement surrounding the sculpture tended to fade by week two, the sculpture transitioned into the background of the household. Despite being less noticed, it still retained its functionality where participants would continue to check the sculpture when they wanted consumption information. This suggests that even after the novelty wears off, the sculpture remains an unobtrusive tool for visualising consumption. On the one hand, the habitual checking of the sculpture, whether before bed or during daily activities, highlights the potential of physical data sculptures to become enduring objects in people's lives, subtly nudging them toward ongoing awareness of their consumption in a non-intrusive manner. On the other hand, it is known that eco-feedback can be effective in the short-term, however, the engagement might wane long-term and can lead to relapse behaviours [41,28]. This balance between blending into the household yet remaining visible for interaction can enhance the engagement with the sculpture. This constant yet subtle reminder [56] can encourage users to gradually internalise the consumption data, facilitating an intuitive understanding of their practices over time.

We noticed the internalisation of understanding happens in relation to the feedback method. Household H4's experience highlights how different feedback

methods, visual and numerical, can shape users' understanding of their consumption. The household described an intuitive connection with their electricity usage through the visual feedback provided by the rotating bee in the Eco-Garden sculpture. They could "feel" their electricity consumption not by interpreting numbers but by anticipating how much the bee would rotate based on their daily activities. In contrast, the household reported that they understood their gas consumption better through the numerical feedback provided through the mobile application. By entering numerical readings, this triggered self-reflection that helped participants develop a sense of familiarity and connection with the data, allowing them to "feel" their gas consumption in terms of numbers. This contrast illustrates the strengths and weaknesses of each method. Visual feedback, such as the rotating bee, provides an intuitive, immediate, and continuous understanding that blends seamlessly into the user's daily life, where users do not need to actively seek out information. In contrast, numerical feedback offers a more detailed understanding but requires more active engagement, and effort to track and interpret data. This may suggest that visual and physical feedback systems might be better suited for promoting intuitive awareness, while numerical feedback may be more appropriate for those seeking detailed, quantitative insights into their consumption. The combination of both methods can enable a richer, more comprehensive understanding of consumption data.

## 8 Limitations and Future Directions

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 [9,25,39,23]). Our study's participants came from a variety of backgrounds and had a range of household sizes, socioeconomic backgrounds, and viewpoints. However, future studies might benefit from directly including children to understand their preferences and need for physical data visualisation design, as we investigated their preferences through their parents.

Although we only performed our study for three weeks with each household ($N = 15$), short-term qualitative research is not uncommon (see [51,49,21]). However, future research may benefit from conducting a long-term study to understand the prolonged engagement of participants with eco-feedback technology [41,28]. In addition, conducting research in participants' households provided valuable contextual insights but also introduced practical challenges common in in-the-wild studies. For instance, H14 had an immovable refrigerator that hindered data collection. Technical issues also arose, such as a child in H10 accidentally switched off a smart plug, and children in H12 played with the Eco-Garden prototype, leading to wiring issues that required reinstallation. Some participants hesitated to share consumption data due to privacy concerns, fearing reporting to energy providers. However, researcher discussions about data confidentiality helped build trust and encourage open conversations.

## 9 Conclusion

Promoting sustainability in everyday life requires systems that make resource consumption tangible and engaging. Physical data visualisations offer interesting ways to visualise household consumption, transforming abstract numbers into engaging and physical forms. We present Eco-Garden, a data sculpture that demonstrates the potential of combining digital and physical feedback systems to promote sustainable practices in household contexts. Through a blend of ambient and child-friendly visualisations, Eco-Garden encourages users to engage with and reduce their consumption of electricity, gas, and food waste. Eco-Garden offers features including goal-setting and disaggregated data display that facilitate households' understanding of resource usage, while its aesthetic and peripheral presence in shared spaces subtly integrates eco-feedback into daily life. Findings from our three-week field study with 15 households suggest that Eco-Garden's design fosters an enhanced understanding of data, making resource usage an approachable and shared commitment.

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