Understanding the Initial Journey of UX Designers Toward Sustainable Interaction Design

A Focus on Digital Infrastructure Energy Reduction

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ABSTRACT

Environmental sustainability is increasingly important, and actions on "digital sustainability" are expanding to reduce energy consumption from digital infrastructures. As many digital services today have extensive user bases, exploring sustainable design features holds significant potential for reducing environmental impact. However, further exploration of foundational research is still necessary to enable broader and more effective adoption of digital sustainability in design practice. This study focuses on understanding important considerations when encouraging more designers, especially those with limited expertise in sustainability-oriented design, to integrate sustainable practices into digital services—acknowledging that embracing unfamiliar approaches presents natural challenges. We conducted design workshops and debriefing interviews with user experience (UX) designers unfamiliar with design for sustainability to explore their early encounters with sustainable interaction design (SID) in the context of digital infrastructure energy reduction. Our study provides insight into designers' initial perceptions and challenges with sustainable design and discusses opportunities for their broader engagement.

CCS CONCEPTS

• **Human-centered computing** → **Empirical studies in HCI**; • **Social and professional topics** → **Sustainability**.

KEYWORDS

Sustainability, Sustainable Interaction Design, Digital Infrastructures, Sustainable HCI, User Experience Design

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1 INTRODUCTION

Digitalization has been deeply integrated into people's lives, and advanced technologies such as cloud computing, artificial intelligence (AI), and blockchain technology continue to emerge. However, the integration of these technologies has led to an increased environmental footprint associated with people's daily digital activities [1, 44, 86]. Coupled with a global trend of escalating digital dependency [44, 56], energy consumption by digital infrastructures such as data centers has emerged as a significant factor in worsening environmental problems [20, 32, 80], notably climate change [49]. This is more broadly referred to by the term "digital (carbon) footprint," which generally denotes carbon emissions resulting from "building, delivering, and using" digital technologies [85], particularly the dominant influence of data centers [75]. Over the past few decades, digitalization has brought significant environmental benefits by replacing material and resource consumption, but now it has become an environmental liability. Known as the "Jevons paradox" [40], improvements in technological efficiency have accelerated digitalization [64] and boosted digital consumption [65], leading to a rebound effect [67] where the environmental benefits of digitalization are overtaken [83]. To continue to use and engage with technology, there is a growing recognition of the need to look beyond the benefits of digital technology, acknowledging its negative environmental impacts and considering responsible practices.

In this context, in the human-computer interaction (HCI) field, several studies have taken various approaches within a subfield called sustainable HCI (SHCI). Many researchers in this field have explored the environmental impacts of digital technologies, addressing issues such as digital infrastructures [38, 51, 64, 65, 75], material waste [41, 52], and device power consumption [37, 76, 82]. While all these areas are significant, the primary focus of our research is specifically the environmental impacts of digital infrastructures. Within this focused area of study, while there are numerous environmental impacts associated with digital infrastructure—including extensive effects related to the mining for physical infrastructure [17]—our research primarily concentrates on the energy consumed

by data storage, transmission, and processing activities. Design approaches for environmental sustainability include persuasive technology [23, 33], ambient awareness [35, 69], and sustainable interaction design (SID) [7, 55, 74], which mainly aim to change digital behavior or usage patterns to more pro-environmental digital use. SHCI community has worked with visions to expand the practical impact, as Priest et al. [64] stated: "all designers have a responsibility to be aware of, and mitigate where practical, the environmental impacts of their work." These visions are built with the good intention that all designers should take responsibility and action to help our society move toward a better environmental future. However, despite its ideal goals, design approaches for sustainability are still not as well recognized, addressed, or taught in the field of UX design (i.e., as other "design approaches for a better future," such as design for accessibility). Currently, design efforts for environmental sustainability are limited to expert groups, including the sustainability-related divisions of a few global companies such as Google, Microsoft, and Netflix [12, 58, 87].

In particular, in this era of widespread digital use and rapid technological development, actively and broadly expanding design approaches that consider its environmental impacts beyond academia into real-world application can be valuable in terms of practice for a better future environment. However, recent studies in fields such as HCI, marketing, and psychology commonly regard the low level of awareness of digital carbon footprints among people (e.g., digital natives [28] and digital users [8]) as a problem [42]. This suggests that, except for a few people with specialized knowledge and experience in the environment or sustainability, many people still lack awareness of the impact of digital carbon footprints. These findings on low awareness were mainly discussed from the perspective of digital users, but we assumed that this could also be true for most designers. This lack of awareness could be an example of the hurdle that makes it difficult to translate the academic vision that all designers should be aware of and to put the environmental responsibility of their work into practice. Inspired by these considerations, we wondered if sustainable interaction design (SID), which advocates for many designers to engage in sustainability, offers a viable approach for designers across various fields. We wanted to learn how designers without much experience in sustainability-oriented design perceive and approach design for sustainability, as well as what obstacles they encounter along the way. Although many studies have focused on the experiences of end users who accept and use sustainable design, there is a lack of understanding on how designers perceive SID and what challenges they face in trying it. Furthermore, many studies have repeatedly argued that sustainable design requires a deep understanding and consideration of existing usage scenarios and usage contexts in order to have a meaningful impact [11, 21, 82]. In this respect, we note that UX designers are good candidates with the potential to propose acceptable and applicable SID solutions, as they have the expertise to deeply understand and follow-up on the existing usage patterns and detailed experiences of digital users. However, few studies have expanded on the perspective beyond sustainability-related experts to more general UX designers.

In this regard, our study aims to identify the perceptions and difficulties of design for sustainability among UX designers who are attempting sustainable design for the first time. The term "sustainability" in this work focuses, among other facets, on the environmental aspect of reducing the energy consumption of digital infrastructures. To explore the perceptions and experiences of UX designers in the early stages of adopting design for sustainability, we conducted design workshops employing various strategies to help them understand and apply SID. In this paper, we present how designers first attempt a design approach for sustainability, identifying their perception of sustainable design and its difficulties. Based on this, we discuss opportunities for broader engagement of UX designers in sustainable design and ways to support their design approach toward sustainability. We anticipate that our research will provide an overall understanding to lay the groundwork for extending sustainability-oriented design beyond experts to a broader range of UX designers, enabling them to effectively consider digital sustainability within the existing design processes of various digital products.

2 RELATED WORK

2.1 Environmentally Sustainable HCI Field and Design Approaches

In the field of HCI, a subfield called SHCI emerged from two foundational studies presented at CHI 2007 [7, 55]. Within the field of SHCI, topics related to environmental sustainability include a wide range of sustainable approaches [18, 36], including energy [45], water [47], and food [61], as well as efforts to contribute to sustainable development with HCI expertise. These studies on environmental sustainability encompass psychological, computer-mediated communication (CMC)-centered, and design-centered approaches [18].

Among them, research on sustainability through design has recognized designers' responsibility in guiding users to act in more responsible and sustainable ways. This perspective mainly focuses on changing individual behaviors, with the goal of encouraging users to act in a more environmentally friendly way [18]. However, this approach has faced criticism, especially the assumption that providing people with information will automatically lead them to make sustainable choices [11]. Eco-feedback systems are a prime example of this approach, aiming to change individual habits by providing users with detailed information about their energy use and encouraging them to think and cut down on their energy consumption [14, 22, 36, 37, 90, 91]. Despite the potential of eco-feedback systems, the idea that individual users could make logical decisions has been challenged. Research has shown that people often act based on habit or without much thought [63] and are less likely to change their habits if it means putting in a lot of effort or making big changes [21, 28, 82]. This highlights the disconnect between what people say they care about and what they actually do [73, 84], pointing out the need for strategies that go beyond just appealing to people's good intentions to achieve real change toward sustainability [19, 25].

Acknowledging these challenges, there is a growing emphasis on the importance of considering UX in sustainable design. It is crucial to understand and fit into existing digital practices and intentions when introducing sustainable solutions [11, 82]. These solutions should also avoid demanding too much from users or reducing the quality of their experience [21]. Despite these discussions, research

on how to effectively integrate UX principles into sustainable design approaches is still lacking. To date, some efforts have been made to develop design rubrics containing guidelines and directions to help follow important considerations in the sustainable design process [7, 64, 67]. As another approach to considering the UX perspective within a design for sustainability, we explored the context in which more UX design experts are adopting and trying out these sustainability-focused design approaches. Our work focuses on understanding how UX designers across various fields perceive and adopt sustainability-focused design approaches, considering their scope and capabilities rather than just sustainability experts.

Within the SHCI field, designs for system change have often been called for as approaches to individual behavior change have been criticized [10]. This systematic approach seeks to reach broader community engagement [43] and societal change [26] beyond individual personal contexts—supporting activism and mass movements and efforts to influence institutions and policies [26, 46, 78]. In this context, our research was driven by an interest in understanding whether and how general UX designers within their design practices could effectively embrace SID approaches, which ultimately serves as an important step toward exploring how digital service corporations can systematically implement SID interventions.

2.2 Design Approaches for Energy Consumption in Digital Infrastructures

Our work focuses on reducing energy consumption from digital services' infrastructure, such as data centers and network systems, within the broader scope of digital carbon footprint [28]. This term also includes the disposal of physical electronic devices [5, 41, 54] and their direct power consumption (e.g., power consumed in the home environment) [5, 76], but our study specifically targets the infrastructure aspect.

Several discussions have been made about the environmental impact caused by digital infrastructures [4, 6, 53, 71]. The Jevons paradox [40] highlights how increasing technological efficiency can speed up digitalization [64], increase consumption [65], and lead to a situation where the environmental harms outweigh the benefits. With this growing environmental impact, research on reducing the digital carbon footprint has expanded in academia. Lord et al. [51] investigated the daily usage practices of mobile devices (smartphones and tablets) and their infrastructure energy consumption, proposing design interventions to reduce energy consumption. Preist et al. [65] quantitatively identified the cloud energy requirements according to user practices and proposed strategies to reduce data demands. Although Bates et al. [5] did not focus on the digital carbon footprint, they highlighted the environmental impact of constant cloud service communication and the need to understand how much communication is truly necessary to support UXs and reduce energy use.

In addition to studies presenting design implications, research has also been conducted to understand users' views on sustainable digital use. For instance, Elgaaied-Gambier et al. [21] studied how aware people are of their digital carbon footprint and how responsible they feel for the environment. Péréa et al. [66] investigated how IT users perceive digital sobriety, and Gnanasekaran et al. [28] focused on digital natives, examining their awareness of the environmental impact of digital usage and the means to motivate them for pro-environmental behavior. Efforts have also been made to provide principles or guidelines for sustainable design and to help integrate sustainability into the design process. Notably, Preist et al. [64] focused on the impact of design on the carbon footprint of cloud services, expanding the traditional design rubric centered on physical material (Blevis' [7] Rubric of Material Effect) and presenting the Rubric of Infrastructural Effects. They presented and explained five critical questions that designers should consider during the design process to reduce the digital carbon footprint caused by the infrastructure of digital services, and they provided basic guidelines for design for digital sustainability. In our work, design for sustainability aligns with the field of SID, where, as highlighted by the works of Blevis, Preist, and Schien [7, 64], design is leveraged as a "critical lens" in addressing the environmental challenges within existing HCI practices [34].

3 METHODS

The purpose of this study was to understand UX designers' perception of the design approach considering the digital sustainability of digital services and the difficulties in the design process. In particular, we focused on the context in which UX designers unfamiliar with designing for sustainability attempt this approach.

3.1 Participants

Through the study, we expected to identify the perceptions and difficulties of UX designers who are unfamiliar with sustainability-oriented design regarding sustainability when they first attempt this approach. Therefore, our study recruited participants who met all of the following criteria: 1) have UX design expertise, 2) have been directly involved in a UX design practice/research project, and 3) have no design experience related to environmental and sustainability expertise. To ensure the appropriateness of the participant conditions, we used a recruitment survey to collect information about the participants, including their demographic information, current occupation, previous experiences in UX design practice/research projects, level of knowledge about environmental issues and sustainability, and understanding of the energy consumed in the operation of digital services. Based on the responses from the survey, we prioritized applicants who met the participant criteria for our study and had more experience in UX design practice and research projects. We sequentially adjusted their participation schedules to determine the final group. Finally, we conducted a total of five design workshops with 15 designers in teams of three (Table 1).

3.2 Study Procedure

Our study consisted of design workshops and debriefing interviews, with the entire process conducted separately for each team. Participants were divided into groups of three, and in each team, the first author (participating in all teams) and the second author (selectively participating in three teams) were additionally involved as moderators. The study process of each team took approximately 2 to 2.5 hours and was recorded with prior consent.

In advance of the design workshop, we created written materials to stimulate participants' design ideas for sustainability. Although

Table 1: Summary of participant information

Team	ID	Age	Gender	UX Design Project Experience
Team 1	P1	25	F	- Artificial Intelligence Video Service Planning - Blockchain-Based Recruitment Support Service UX/UI Design
	P2	28	F	- Digital Healthcare Service Design - In-Car Agent Embodiment Design
	P3	28	M	- Emotional Remote Communication System Design - Speculative Design on Human–Nonhuman Relationships
Team 2	P4	27	M	- Proactive Agent Interaction Design within TV - Chatbot Design within Mobile Stock Service
	P5	29	F	- Mobile Stock Service UX/UI Design - Accessibility Design for Video-Mediated Communication
	P6	32	F	- AI-Based Sleep Habit Improvement Service UX/UI Design - Teaching–Learning Interaction Design for Intelligent Systems
Team 3	P7	27	F	- Diet Regulation Service Design to Assist Eating Disorders - Algorithm Design for Online Dating Services
	P8	25	F	- Stock Information Provision Service UX/UI Design
	P9	33	F	- Physio Sensor-Based Digital Product Design - Voice Interaction Design for Conversational Agents
Team 4	P10	28	F	- UX/UI Diagnosis for Corporate Digital Marketing - Local Business Commoning Design
	P11	25	F	- Education/Entertainment Service UX Planning - Smart Kiosk UX/UI Design
	P12	29	M	- Mobile App UX/UI Design and Development for Coding Education - Mobile–IoT System Development
Team 5	P13	25	M	- Tablet-Based Service UX/UI Design in Autonomous Vehicles
	P14	30	F	- Mobile Financial Service UX/UI Design - Social VR Content UX/UI Design
	P15	25	M	- Mental Accounting-Based Interactive Asset Managing Service Design - Human–LLM Interaction Design

it was possible to observe the frustration and ambiguity that participants may experience in the early stages of designing for sustainability without additional materials, we decided that providing enough basic support to observe discussions between participants in the process of discovering and defining design ideas would be helpful in eliciting their inherent perceptions and perspectives toward designing for sustainability. The first and second authors developed this material by collecting and structuring knowledge and design suggestions related to sustainable design already mentioned in previous literature [8, 11, 21, 24, 28, 36, 39, 48, 51, 65, 66, 76, 82]—extracted mainly from the literature through the keywords "sustainable HCI," "sustainable design," "digital sustainability," "persuasive design," and "Green IT." As a result, the following three types of information were organized into a one-page document each: 1) User tendencies toward sustainable design; 2) Implications for digital sustainable design; and 3) Examples of digital sustainable design (see Appendix A). These materials are provided to help participants with a limited understanding of digital sustainability (the topic of the workshop) understand the scope of SID concepts covered in our study and provide insights to stimulate ideation.

The design workshop aimed to understand the participants' experience of exploring and discussing SID ideas that can be applied to various digital services—focusing on sustainable solutions in terms of reducing digital infrastructure energy consumption. First, the moderators held a Warm-Up Session with the participants, including self-introductions. Then, the first author introduced the background, purpose, and process of this study, as well as the specific scope to be explored in the workshop, including the definition of digital carbon footprint and SID with design examples [79]. Additionally, to encourage active participation and discussion, we specified that it was okay to struggle with the design process because this study was not a workshop that necessarily required expert knowledge related to digital sustainability or SID. Afterward, in a 5-minute Target Service Listing Session, we asked each participant to individually list the digital services they were currently using. We did not limit the target services to be covered in the workshop, anticipating that this might lead to a sense of uncertainty among the participants when selecting a design subject. Exploring sustainable design ideas across a range of digital services, rather than targeting a specific service, is not a typical context in practice beyond the workshop; therefore, we proceeded with this

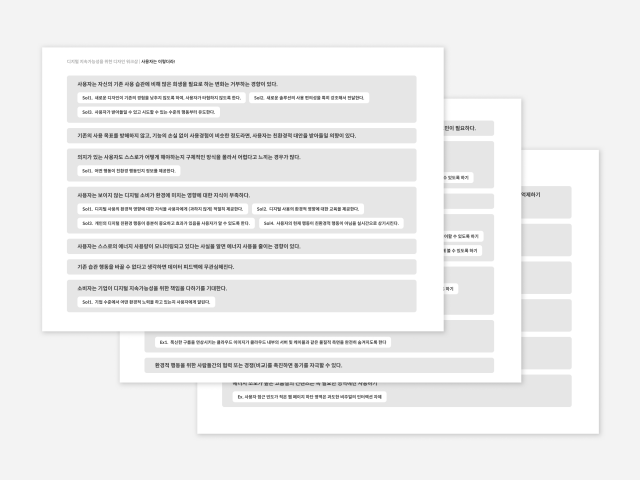

Figure 1: Three pages of workshop materials summarizing sustainable design knowledge, principles, and examples (detailed content available in Appendix A)

stage as a strategy to alleviate these anticipated initial difficulties. We then conducted a 30-minute Ideation Session where participants were asked to divergently write down sustainable design ideas applicable to existing digital services on sticky notes. Participants were allowed to freely use their personal laptops and smartphones during this session, which we had asked them to bring in advance. When expressing their ideas on sticky notes, participants were asked to include a design idea in the form of a simple sentence or phrase, along with the name or type of digital service associated with that idea. This ideation process was essentially an individual task, but conversation and sharing of opinions among participants were freely allowed. Five minutes after the Ideation Session began, the moderator distributed to participants three document-type materials, including basic knowledge that can be used as a reference for SID (Figure 1). This was to ensure that our materials did not directly limit the direction and scope of participants' ideas from the beginning of the ideation process. These materials were not presented to the participants as a fully structured classification system but as resources for reference and inspiration, acknowledging the possibility that they may contain information not pertinent to the current context and emphasizing that there is no obligation to use them. We did not give a separate reading time to familiarize participants with these materials; instead, they were free to refer to them throughout the Ideation Session as needed. Subsequently, an Idea Review Session was conducted for 1 to 1.5 hours to share and develop each initial idea. In this session, discussions were held on each idea, including the design details, the pros and cons in terms of digital sustainability and user experience, and any concerns.

Immediately after the design workshop, a 30-minute Debriefing Interview Session was conducted to ask participants about their thoughts and challenges regarding their experience exploring design for sustainability. The interview consisted of the following five questions: 1) "What was the overall experience of thinking about design for digital sustainability?"; 2) "What was particularly difficult in the ideation process of design for digital sustainability?"; 3) "How can we improve today's workshop to be better?"; 4) "What difficulties are expected if sustainability goals are included in actual design practice rather than in the form of a one-time workshop?"; and 5) "As a designer, what do you think is needed to do better at designing for digital sustainability?"

3.3 Data Analysis

After all teams' design workshops and interviews were completed, the first author transcribed the entire recorded audio and organized the idea listing documents discussed in our workshop by team, referring to the content participants wrote on sticky notes during the study. The authors reviewed the entire transcripts with memoing in order to be immersed in our workshop data [15]. Afterward, we conducted thematic analysis [27] by following the six phases of thematic analysis suggested by Braun and Clarke [9]. We coded with the goal of deriving interpretations of the designers' workshop experiences found in the transcripts, focusing on participants' workshop participation methods and tendencies, their perceptions of sustainable design, problematic situations, and further requirements. In particular, we noted topics that participants emphasized or mentioned repeatedly during the study in order to be considered important and revisited them repeatedly until the final theme was selected. We derived the final themes through the process of adding, deleting, and revising initial codes. Finally, we structured the themes by differentiating between the designers' perceptions and difficulties regarding the SID observed in the workshop.

4 FINDINGS

In this section, we report the findings of our study, focusing on participants' perceptions of SID in digital services and the difficulties they encountered when first attempting this approach. This study focuses on providing an understanding of the experiences of UX designers who are unfamiliar with SID as they explore design ideas that can reduce digital infrastructure energy consumption.

4.1 UX Designers' Perceptions of Adopting Sustainable Interaction Design

The workshop revealed two major characteristics in UX designers' initial perceptions of adopting SID within digital services. First, most of our participants perceived SID as a challenging domain extending beyond the boundaries of conventional UX expertise. This approach was recognized as necessitating richer environmental support and the establishment of more robust design practices. Second, along with the perception that this approach is challenging, some participants found that after experiencing the workshop, contrary to their expectations, they saw the SID approach as an accessible and valuable area that requires in-depth UX expertise. Despite being a one-time workshop, the fact that this endeavor encouraged to shift the perception of some designers regarding design for sustainability presents an interesting finding.

4.1.1 Challenging Area Beyond the Boundaries of Conventional UX Expertise. When UX designers began to approach design for environmental sustainability, these sustainable design attempts were perceived as challenging and apprehensive. Our participants had no previous design experience considering aspects of digital

sustainability within the design process, so designing for sustainability was a fresh and unfamiliar topic for all of them. Although attempting such an unfamiliar approach naturally carries tension and challenges, our results particularly highlight that UX designers anticipated this approach as beyond their normal scope and one where they felt unable to showcase their skills effectively. At the beginning of the workshop, some participants understood SID as a task that was (completely) different from their specialty, UX design, which led to a lack of confidence and passivity. They had low expectations that they could use their expertise to produce meaningful results for the workshop. For example, P4 said, *"I don't really know much about this field. I came here thinking I wouldn't have any ideas today."* This perception that design for sustainability is an area outside their expertise and their low expectations about their capabilities were particularly strong in the early stages of our workshop.

Furthermore, most of the participants in our study had low awareness of digital sustainability as individuals, beyond their lack of work experience. This low awareness was revealed through participants' responses during the workshop's introduction session and subsequent debriefing interviews. This finding supports our assumption that not just users but also designers would exhibit a low awareness of digital carbon footprints (although this cannot be quantitatively assessed and generalized). The realization that they were not consciously aware of the environmental impact of digital activities in their everyday lives made the participants feel even more incapable of successfully engaging with sustainability-oriented design approaches. This perception negatively impacted their initial confidence in suggesting sustainable design ideas. Many participants, when introducing their ideas during the workshop, used expressions such as *"obvious"* (P11), *"nonsense and worthy of criticism"* (P11), *"ridiculous"* (P15), *"possibly useless"* (P9), and *"not sure if this is a good idea"* (P15). Some participants explicitly expressed the challenges of exploring new ideas within 15 minutes of starting the workshop, stating things like *"I'm a bit stuck now"* (P1), which sometimes led to self-criticism.

> *"I think it would have been better to personally experience being engaged in digital activities with awareness. For example, I could spend a week being conscious of my digital carbon footprint. I mean, a period where I can gather firsthand insights (moment by moment in daily life) on what issues design can address."* (P10)

As the workshop progressed, the perception that design for sustainability was a challenging approach tended to ease. Nevertheless, in the debriefing interviews, participants emphasized that designing for sustainability is (nearly) impossible without environmental and practical support to encourage dedicated efforts. During the workshops and debriefing interviews, many participants repeatedly expressed concern that designing with considerations about digital infrastructure energy consumption is difficult to pursue solely based on individual will, especially if it is not set as a shared goal for their team or company. Participants highlighted the necessity of institutional and infrastructural support as a fundamental basis for driving sustainable design. They felt that without this foundation, it would be impossible to enable sustainable design practices that took digital infrastructure into account under the existing goals of the team and the company. P15 pointed out that, with the exception of a few global companies, environmental sustainability is rarely included as an important value in the design process in many of the current corporate environments, and that additional motivation is essential for this approach to be adopted in practice.

> *"I can't reconcile the (company's) existing interests, I can't. (...) I'd prefer it if regulations were set by the government, so there's a framing (that encourages this approach), like it's a trend to consider digital infrastructure in the design process. (...)"* (P14)

During the workshop, participants also experienced various challenges in design decision-making (reported in more detail in Section 4.2). In particular, the lack of practical design references and decision-making criteria for designers to effectively consider UX and digital infrastructure energy consumption together made it difficult for them to make effective judgments. This left participants unsure about the decision-making process for sustainable design and caused confusion throughout the workshop. They argued that design principles and evaluation methods for sustainable design can differ from those for conventional UX design, which is sometimes essential to apply different criteria. For example, P12 noted, *"The direction of sustainability (...) requires a different approach because it is associated with better social outcomes, even if it means compromising my UX slightly."* P4 said, *"In contrast to traditional UX principles, designing for sustainability may require a new paradigm. For example, there used to be an accepted rule that designs that are negative or guilt-inducing (to the user) are bad (in conventional UX design)"* emphasizing the need for additional practical knowledge and metrics to support design for sustainability in digital infrastructures beyond conventional UX design.

4.1.2 A Design Approach Accessible, Valuable, and Requiring In-depth UX Expertise. Along with the recognition that considering the energy consumption of digital infrastructures is a challenging approach in current practice, several participants (P4, P7, P8, P11, P12, P13, and P14) gradually came to accept it as an accessible and worthwhile domain for them as UX designers. Although not all participants experienced this shift in perception, one interesting finding was that, during a workshop of about 2 hours, there was a noted change from initially perceiving the domain as outside their role and expertise to accepting it as a domain worth exploring and necessary. This section focuses on how some participants interpreted and empathized with the value of SID through the workshop.

Participants explored and discussed a total of 158 design ideas, gathered across five workshop sessions. (Recognizing that it is nearly impossible to accurately measure the resulting digital infrastructure energy consumption of design ideas [81] and that workshop participants are not sustainability experts, some design ideas are likely to be unimplementable or have no environmental benefit, but all ideas that generated meaningful discussion were counted.) Most ideas were aimed at reducing infrastructure energy consumption without excessively compromising the existing user experience, but, interestingly, ideas were often presented that not only had environmental potential but enhanced UX by addressing pain points for existing users. The discussion of these ideas provided new insights for participants and exposed them to the possibility that sustainable design, which is often thought of as the antithesis of improving

user experience, can actually be both UX and environmental sustainability.

For example, Team 5 proposed *"an option to set the main page of a banking app to retrieve data only when the user takes action to view asset information"* in order to prevent the exposure of financial information in public. This was addressed as a way to improve UX while saving infrastructure energy by preventing unnecessary data loading for the user. As other examples, the following ideas were presented: *"Providing an option to recommend deleting all empty documents after a certain period of time, such as 'Untitled' (Notion, Google Drive, Figma)"* (Team 1); or *"Introducing a binge-watch mode in video streaming services; when this mode is turned on, it would automatically skip all openings, download the next episode, and seamlessly play it (Netflix, Disney+, Tving)"* (Team 3). Team 1's idea was a result of solving the hassle of manually deleting pages that users no longer need (P1's personal experience) while reducing unnecessary data storage. Team 3's idea was to support the user's continuous video-watching experience while allowing them to automatically download videos at times of low traffic to enable energy-efficient data transfer compared to live streaming. When discussing sustainable design ideas that could improve the existing user experience, many participants (P1, P4, P5, P6, P7, P8, P9, P10, P11, P12, and P14) expressed their personal desire to add these features to existing services. Although most participants expected before starting the workshop that SID would be a process that requires completely different discussions from general UX design, through the discussion of the workshop, some participants gradually accepted SID as an area where UX designers have the potential to explore design features that benefit both UX and environmental sustainability. They acknowledged that there was an area of environmentally and user-friendly design that had not yet been fully explored and that there was a need for design approaches that consider the environmental sustainability of digital infrastructures. Quoting P1, they came to understand that *"it's not fundamentally different from how we think about traditional UX in the grand scheme of things."*

> *"I thought there could be more opportunities in something more common and routine than we thought. And I think it's kind of like, 'Oh, there's so many things that could be good for me (the user) in a lot of ways (in terms of experience),' but at the same time, there're so many things that could be good for sustainability."* (P11)

Furthermore, we found that they tended to recognize and appreciate the importance and meaning of UX designers' approach to designing for sustainability itself. They thought that UX design professional skills can play an important role in presenting design changes for sustainability without inducing resistance from users and an important role in driving *"unconscious behavior change"* (P8) in users. In particular, through a process enriched with discussions not only on sustainability perspectives (e.g., which ideas are more energy efficient) but also on user-centric considerations (e.g., what considerations are needed to ensure that the idea fits harmoniously within the usage journey of existing users), participants focused on the explorability of solutions that pursue both UX and environmental sustainability.

Most participants shared that they were largely unaware of the impact their designs had on the energy consumption of digital infrastructures before the workshop. The information presented through the workshop's introduction session and materials provided participants with a new awareness of environmental impacts, which in some cases contrasted with their existing understanding. In particular, misconceptions about the energy consumption associated with video streaming versus downloading were revealed as a representative example. In the words of P9, *"Downloading feels like it consumes more energy and feels more intense than streaming."* The experience of confronting the environmental impact of their designs for the first time was an awakening for the participants, prompting them to reflect on the importance of designing with an awareness of digital infrastructure energy consumption. P7 commented, *"I didn't realize all this stuff—that it takes a lot of energy to store this (data). I just thought it was annoying that this video (I didn't even want to watch) was playing (automatically), but I didn't realize that it could have a bad impact (environmentally)."*

4.2 Difficulties in Adopting Sustainable Interaction Design

Along with designers' initial perceptions of SID, we found that UX designers face various difficulties in trying and adopting SID within digital services for the first time. This can be a natural challenge people experience when attempting an unfamiliar task for the first time. We aim to identify obstacles to considering digital sustainability in the digital service design process, especially for designers who lack experience in designing for environmental sustainability. In this section, three types of difficulties are presented: 1) Difficulties in Initial Engagement and Focus; 2) Challenges in Technical and Environmental Decision-Making; and 3) Psychological Hurdles. Each difficulty is presented in two to three detailed aspects, a summary of which is presented in Table 2 at the end of the section.

4.2.1 Difficulties in Initial Engagement and Focus. One of the initial difficulties when first approaching SID in terms of digital infrastructure energy consumption was made by the nature of the concept of sustainability and a lack of relevant design experience. These difficulties can be a significant barrier to designers' first attempts at SID and to immersion in this design approach. This difficulty, "Difficulties in Initial Engagement and Focus," consists of the following three aspects: 1) The overwhelming scope of sustainability; 2) Pressure from the complexity of the sustainability concept; and 3) Insecurity due to lack of experience.

1) The overwhelming scope of sustainability. First, participants tended to be overwhelmed by the use of the term digital sustainability as a design goal introduced in the workshop. In particular, the broadness of the concept of sustainability made it difficult for them to know where to start thinking. The confusion comes from the fact that the design goals that include the term sustainability are too broad and cover a variety of areas. Although our workshop was limited to environmental sustainability issues related to digital infrastructure energy consumption, participants considered this to be still broad. Several participants expressed the difficulty that the use of the term digital sustainability as a design goal, with only the ultimate goal point of "reducing digital infrastructure energy consumption" being presented, allows for too many approaches and ideas at the start.

> *"I think it was hard to come up with at first because there are so many different ways to approach it, like how to just reduce energy consumption (through changing algorithms or processing methods), how to increase user awareness, and so many different ways, so I think the goal needs to be (more) clear."* (P5)

> *"I think it (the goal) seemed daunting to me, so I just kind of defined it in my own mind and thought of it as reducing the amount of water that goes into the data center (...) Once I narrowed it down to a data management level instead of a macro level; I thought it was something I could handle."* (P9)

To overcome this vagueness, participants initially took the strategy of narrowing down and identifying for themselves the scope or detailed goal of reducing the energy consumption of their digital infrastructure. This included a variety of detailed design goals, such as reducing the amount of data generated, enabling better data deletion, utilizing less data when certain features are implemented, reducing the frequency of real-time communication, adjusting the timing of real-time communication, or increasing users' awareness of their digital carbon footprint. Some participants segmented by the target product type, as *"services of the same type, such as streaming services, mail services, tend to have similar UX"* (P6). Some also explored ideas at multiple levels of design intervention, such as *"targeting impacts through detailed changes to the UI, or through changes to the direction or concept of the service itself"* (P4). Narrowing the design scope and goals helped participants translate the concept of digital sustainability, which they felt was too broad, into more specific and practical design goals.

2) Pressure from the complexity of the sustainability concept. In addition to the broad design goal that includes the term sustainability, the pressure to understand and address its profound meaning and significance was also found to be an initial barrier for designers. We found that the term sustainability was perceived by participants as more than just an area they were not familiar with; it carried a weight that made it daunting to tackle and was seen as a complex, broad concept that was difficult to grasp. P9 expressed feelings of being overwhelmed several times during the workshop and said, *"I feel overwhelmed when I hear that the design goal is for 'sustainability.'"* While this burden of conceptual complexity could facilitate deep and careful thinking, it was found to be one of the causes that prevented participants from exploring ideas more freely and effectively. For example, P7 noted, *"When I first came up with the idea, it was too hard, but then I changed it to, 'What are some of the features that have been pushed on me that I don't really need,' and then it became easier to ideate."*

3) Insecurity due to lack of experience. Insecurity due to lack of experience with new approaches was also found to be one of the factors hindering participants' engagement. These initial concerns were due to uncertainty and fear of a new field. This tended to ease as the workshop progressed and discussions between participants became more active. In fact, during the initial ideation process, we observed that participants needed sufficient time due to their lack of experience, but soon after this burden was alleviated, they explored and discussed a variety of ideas more comfortably and sequentially.

4.2.2 *Challenges in Technical and Environmental Decision-Making.*

Another major difficulty that inhibited design discourse was when participants explored and developed ideas with the potential of reducing digital infrastructure energy consumption. In the workshop, we provided some knowledge about user trends, design applications, and design examples for sustainable design based on previous literature (Appendix A), but participants needed more practical, contextual, and detailed knowledge in the ideation process. The practical challenges that prevent smooth discussion of design ideas consist of the following three aspects: 1) Complexity in estimating energy consumption for features; 2) Difficulty in grasping feature development and processing principles; and 3) Uncertainty in evaluating the technical feasibility of design ideas.

1) Complexity in estimating energy consumption for features. In the process of exploring sustainable design ideas, we found that the most critical difficulty inhibiting design decisions was the struggle to estimate the infrastructure energy consumption for each design feature. Much of the discussion and debate during the workshop stemmed from the difficulty of accurately predicting and estimating the actual impact of each design idea on the resulting infrastructure energy consumption. Some participants (P1, P2, P3, and P7) explicitly expressed this confusion as the biggest challenge in designing for sustainability.

> *"This is something that keeps coming up, but I think it's the most difficult thing because I don't know how much influence this has (on infrastructure energy consumption), how much actual effect it has, which of the ideas is better, and so on, and that's why I think it's the most difficult thing."* (P1)

First, the lack of knowledge about the energy consumed to implement existing features made it difficult for participants to determine which features of the existing service could be improved during the initial ideation process. P10 described this lack of technical knowledge as *"making it difficult to define the problem"* for SID. It also prevented participants from answering the fundamental question of whether their solution ideas were truly more energy-efficient than the existing ones. Sometimes, in discussing their ideas, participants were faced with the dilemma that their concepts had the potential to further increase the carbon footprint by introducing additional processes not present in the original design. Participants contended that meaningful design is contingent upon having a thorough understanding of specific technical information, which enables its effective application in their designs. In particular, the lack of specific and reliable data to estimate these energy consumptions not only made it difficult to determine the validity of each idea, but the continued ambiguity also led participants to question the value of their attempts to design for sustainability.

> *"Now, if (the solution idea we presented) causes additional data processing, I think we might need to know the technical implementation process itself in order to think of another way to avoid this."* (P2)

> *"Now we are considering digital sustainability, but we are just thinking and putting it out here without any concrete data, so it's a little bit hard to get a sense of*

> *how effective it is. I'm confused as to whether we are coming up with an idea worth putting effort into."* (P14)

2) Difficulty in grasping feature development and processing principles. We also found that the designers had difficulty understanding the technical development and processing principles of features that are/will be implemented within existing digital services. With the exception of three (P12, P13, and P15) who had development-related knowledge, all participants in our study found it difficult to anticipate how certain features of digital services are technically implemented. Basic knowledge of how these features are implemented was useful information for participants to estimate and compare energy consumption among features (even though it is not accurate) in the process of exploring ideas that are more pro-environmental than existing functions of current services. During the workshop, participants asked questions about the specific processing of existing features, and most participants relied on guesses and intuition to discuss their design.

> *"(For example,) if there are five files (in Google Drive), does it load all five files the moment I log in? Or does it just bring up the list (at first) and then you have to open (the file) and then it brings it up?"* (P3)

Because designers are not necessarily required to discuss these technical aspects in most UX design processes, the participants were unfamiliar with these considerations. As a result, their lack of understanding of technical developments and processing principles presented a new challenge that differed from the general UX design process.

3) Uncertainty in evaluating the technical feasibility of design ideas. Participants also faced a hurdle in determining whether an idea was technically feasible or not. In our workshops, participants struggled to determine if the suggested designs were actually implementable.

> *"Like, I think it would be great to design it this way, but I'm not sure if we can actually develop it. Can it be implemented? Is this a feasible design? I think those parts were huddles."* (P5)

The ongoing uncertainty about whether the various solution ideas presented during the workshop could actually be implemented proved to be a significant hurdle for participants. This was a common challenge that participants often faced.

4.2.3 Psychological Hurdles. Finally, psychological barriers and internal conflicts faced by designers were identified as the main difficulties in the process of design ideation while considering the infrastructure energy consumption of digital services. These psychological challenges add a new dimension of consideration to the design process. This consists of two aspects: 1) Tension between established design practices & profit motives and sustainable design; and 2) Dilemma in aligning user expectations with sustainable design goals.

1) Tension between established design practices & profit motives and sustainable design. We discovered conflicts with existing practices related to the profitable elements pursued by digital companies. For example, this includes the following conventional design directions: keeping users on the service longer and making them addicted; driving more frequent interactions with users, such as increasing the number of clicks or the frequency with which users see ads; and collecting and storing more user data to train models. These conventional design practices often pointed in the opposite direction to the SID ideas proposed by the participants. As designers, participants experienced confusion about how to accommodate and represent the position of each digital service company, while not losing sight of the purpose of the workshop. Some participants also felt that this was a dilemma because these profit factors were not just for the company but also for the performance they wanted to achieve as designers. For example, P9 suggested the idea of *"adding a small indicator alongside the function buttons on the bottom right that counts how many short-form videos you've watched in a row to date"* in the interface that shows Shorts videos on YouTube. The idea is to give users a visible indication of their digital usage so that they can be aware of the amount of content they watch. However, P9 said that if s/he were a YouTube designer, s/he *"wouldn't want to do this"* because of the designer's *"personal performance"* needs. P9 also mentioned, *"I don't want to think about digital sustainability as a designer, so I'd like other departments to take care of that aspect separately."*

> *"Because the number of views is very important right now. If tens of millions, or even millions, of people viewed this, that could be performance, in a way, for YouTube. This is also true as a designer. Because, if I removed this button from Shorts and the number of views increased dramatically, it could be a personal performance number. When I put this button and people started not watching, I thought it would be difficult because of the direction of proper sustainable design and the goals of service providers conflict."* (P9)

As such, finding a balance between existing practices that seek to increase users' digital participation and the constraints required by a pro-environmental approach was a major challenge for participants.

2) Dilemma in aligning user expectations with sustainable design goals. Another psychological hurdle was the hesitation to develop ideas when the direction of design aiming for digital sustainability diverged from the conventional user-centered design approach. This was not true in all cases, but in some cases, ideas that could bring environmental benefits had the potential to harm the existing user experience, requiring exploration of strategies that would not require significant sacrifice of the existing experience. For example, in Team 4, while developing an idea to show users the infrastructure energy consumption of their digital activities, the team discussed how to ensure that this guidance would not detract from the existing digital experience and provide a sense of guilt. As a result, the idea was developed to provide explanatory information that would appeal to users with a desire for digital detox or a need to save battery consumption. On the other hand, we also found that the participants' opinions often contradicted what they pursue as end users and the design direction of their ideas. During the workshop discussion, P10 expressed that *"the things that are required to move towards digital sustainability are things that I don't want to give up as a user"*. This psychological conflict was often found during discussions about how much force or restriction to impose on users. In response to these psychological hurdles, participants recognized

Table 2: UX Designers' Difficulties in Adopting Energy-Efficient Sustainable Interaction Design in Digital Infrastructures

Difficulty	Detailed Difficulty	Description
Difficulties in Initial Engagement and Focus	The overwhelming scope of sustainability	Difficulty in understanding where to start due to sustainability's wide scope
	Pressure from the complexity of the sustainability concept	Feeling burdened by the deep meanings associated with "sustainability"
	Insecurity due to lack of experience	Lack of confidence stemming from not having enough experience with the approach
Challenges in Technical and Environmental Decision-Making	Complexity in estimating energy consumption for features	Difficulty in estimating the energy usage of each feature due to various complex factors
	Difficulty in grasping feature development and processing principles	Challenge in understanding how specific features are technically developed and processed
	Uncertainty in evaluating the technical feasibility of design ideas	Difficulty in determining if a design idea can be realistically implemented
Psychological Hurdles	Tension between established design practices & profit motives and sustainable design	Conflict between conventional design methods that often demand more digital engagement from users, and the necessity to focus on profitability
	Dilemma in aligning user expectations with sustainable design goals	Struggle to balance what users expect from a digital experience with sustainable design

that balancing conflicting factors while appropriately moderating their levels is an important challenge in SID.

> *"As I was designing this, I kept thinking about it from the user's perspective, too, and I think that's where some of the conflicts came in. It was, like, on one hand, I could see the purpose and potential of the design, but then, stepping into the perspective of a user, I realized it might be inconvenient or a bit of a hassle. So, these two thoughts were kind of clashing in my mind."* (P11)

> *"I felt like forcing it is not the way to go, but then again, just leaving it up to individual choice seems like nobody would do it. Finding that balance was really challenging, and that's why I started thinking about ideas like organizing events or running campaigns to kind of nudge people in the right direction."* (P6)

5 DISCUSSION

Through this study, we discovered that UX designers new to designing for sustainability perceive this design approach as a challenging domain that extends beyond their area of expertise. Meanwhile, the workshop enabled several participants to recognize this approach as an accessible and worthwhile field. The fact that a short but immersive experience of exploring and discussing design approaches can expand the way designers view design for sustainability seems like an opportunity to encourage more designers to engage with sustainability-oriented design. In this section, we discuss our recognition of these opportunities and ways to mitigate the challenges and hurdles for UX designers unfamiliar with these approaches.

5.1 Potential for Broader Engagement of UX Designers in Design for Sustainability

Our workshops provided UX designers with an intensive experience of recognizing the environmental impact of digital infrastructures and exploring and discussing design features that have the potential to reduce it. Our findings show that this brief yet impactful initiative to explore sustainable design ideas can encourage some UX designers to recognize that efforts to consider digital infrastructure energy consumption within the UX design process are an important and worthwhile approach. Because the meaning of sustainability and thoughts about its application are complex issues that rely heavily on people's personal beliefs and values [62], there was no expectation that consistent perceptions would be observed across all designers in our study. Given that designers are also digital users, our expectation was based on the findings of Péréa et al. [66], who identified five different levels of users' perspectives on digital sobriety. Accepting these differences in personal perspectives on sustainability, we note that the experience of our workshop positively influenced several designers' perceptions of sustainable design, even though the designers faced very different challenges during our workshop and, in most cases, made unsatisfactory design decisions based on guesswork.

Previous research has mostly emphasized the low awareness of digital carbon footprint among digital users [8, 28, 42], and our findings show that designers also lack awareness of this issue. Designers who were influenced by the workshop experience to acknowledge the positive value of sustainable design were particularly interested in the fact that they had previously been unaware of the negative impact their design work could have on the environment. This

realization opened up the possibility of thinking in a direction that they had not previously considered. This relates to Nieminen et al.'s remark that good designers understand the impact of their designs [60], where "impact" initially referred to the effects on users, and our results demonstrate designers' interest in and willingness to understand the broader impact. In this respect, we see the possibility of increasing designer awareness of digital carbon footprints and their greater participation in designing for sustainability.

In the field of SID, the need for connections with the professional UX field has been discussed consistently [18, 36]. More recently, a few global companies have recognized their responsibility for the negative environmental impacts of their digital products, and as part of various pro-environmental efforts, design interventions within their digital products have emerged. For example, Google reported that several sustainability features, including the eco-friendly routing feature within Google Maps, "prevented more than 1.2 million metric tons of carbon emissions from launch through 2022" [29]. As in the case of Google, some designs can actually help the environment; however, others may have no real benefit or even backfire despite being designed with the environment in mind. These issues were identified in our study as an obstacle preventing designers from making confident and rational decisions. However, we believe that designers should have awareness of and empathy for SID's orientation, be aware of the environmental impact of their work, and act on it if necessary before moving on to the discussion of what is actually a good, sustainable design. Taking accessibility design as an example, some designs can genuinely help people with disabilities, whereas others, despite having good aims, do not help them or even have the potential to discriminate. Nevertheless, as designers become more aware of and sympathetic to the need to consider accessibility in the design process, we see more examples of good accessible results. In this context, our findings were noteworthy, showing that through a short workshop, even general UX designers, who do not specialize in this area, can understand and see their UX expertise as accessible and valuable in addressing the environmental impacts associated with digital infrastructures. This realization underscores the potential for broader engagement within the professional UX community toward SID, reflecting an understanding and appreciation of the environmental dimensions of digital product design.

5.2 Addressing the Initial Challenges of UX Designers in Designing for Sustainability

At the same time, our findings on various difficulties in the design process for sustainability show that encouraging more UX designers to design for sustainability comes with several difficulties. In particular, for participants who consistently held challenging perceptions of existing SIDs, these difficulties made sustainable design seem even more out of their reach. The main difficulties were a lack of knowledge and resources to make rational design decisions and psychological hurdles that conflicted with existing design practices. Although some have viewed these rising challenges as a positive factor in maintaining creative engagement with the task [16], the difficulties we found in our study acted as a negative factor for participants, slowing down and confusing the decision-making process of the design task.

Our research highlights the importance of setting specific and segmented goals for designers new to SID. A broad goal of reducing the energy consumption of digital infrastructure can make it difficult for designers to generate practical ideas at the early stage. While this finding of difficulty may be a limitation of our workshop setting, these activities will likely be included and described under the broader concept of sustainability, even as this extends beyond the limited workshop setting and into practice. This possibility is supported by the current practice where the terms "Sustainability [2, 30, 59]" and "Environment [3]" are used by teams formulating better environmental strategies in organizations. While broad goals could allow for exploring different perspectives and approaches, our findings underscore that the participants actively narrowed down to more specific and practical goals and approaches, indicating a clear need for concrete objectives to facilitate effective idea generation. Further research on understanding specific design improvement directions or approach strategies that are useful for reducing digital infrastructure energy consumption could provide well-defined design goals. Detailed design goals specified by designers in our workshop, as presented in Section 4.2.1, serve as good examples. These include reducing the amount of data generated, enabling better data deletion, utilizing less data when certain features are implemented, reducing the frequency of real-time communication, adjusting the timing of real-time communication, and increasing users' awareness of their digital carbon footprint. Narrowing the scope of the goal by targeting specific usage scenarios or personas can also help designers in participating in more effective initial engagement.

Next, we identified various technical and environmental decision-making challenges as the most common difficulties preventing UX designers from designing rationally. This consists of difficulties in estimating specific processing methods and energy consumption for each design feature within digital services and identifying the feasibility of design ideas. To support this problem, the developmental and environmental knowledge needed in the decision-making process of designing for sustainability can be provided in a form useful at various stages of the design process. Reflecting the suggestions by Remy et al. [68] that delivering knowledge of SHCI design would be helpful in the early stages and specific tools or applications in the later stages of practical SID solution exploration, we further specify and expand this. Design for sustainability requires multidisciplinary knowledge that is not typically required in traditional UX design decision-making processes. Recently, these challenges have been faced similarly in the field of service design that applies advanced technologies such as AI/ML, and researchers have emphasized the importance of promoting collaboration with experts from other disciplines (especially technology) [50, 88, 89]. In designing for sustainability, we also suggest that it would be useful to facilitate collaboration with experts in the technical and environmental fields to supplement knowledge beyond the expertise of UX designers. This proposal aligns with the ongoing call for multidisciplinary expertise and collaboration in the SHCI community [13, 77, 78], as summarized in the review article by Bremer et al. [10]. In addition, although tools for assessing the complex carbon footprint of digital products for sustainable development in SHCI have been actively developed and used in practice [72], limited focus has been paid to tools from the perspective of designers

and in support of sustainable decision-making within their design process. Similarly, to support designing with AI, Google's People + AI Research (PAIR) team has produced open-source tools and a practical guidebook [31]. These examples are built on data and insights from industry experts and academic research in the field of AI design, conveying a level of knowledge that design practitioners can understand and utilize—good examples for us to follow. In particular, the guidelines could effectively address and clarify the characteristics of designing for sustainability, which our participants found confusing due to their distinct nature from traditional UX design. For this, additional research is needed to contextualize the lessons and decision-making cases of experts with sufficient experience in sustainability design. This aligns with Preist et al.'s [64] call to the SHCI field for further research that can be used to develop accessible guidelines for the design considering digital infrastructures. Furthermore, these guidelines should not only consider the energy consumed by specific design features but also encourage speculation on various secondary outcomes that these changes might induce related to the rebound effect. For example, the "binge-watch mode in video streaming services" introduced by Team 3 in Section 4.1 could slightly reduce the energy consumption caused by individual users streaming multiple episodes consecutively. However, this experiential convenience might inadvertently encourage more users to watch streaming videos, increasing overall usage. It is essential, therefore, to prepare and make efforts to include aspects in the guidelines that enable designers to contemplate both the direct implications of their designs, such as the impact on energy consumption in digital infrastructures, and the broader potential secondary results. Such preparation is crucial for designers to better understand the "real" impact of their design decisions.

In the process of designing for sustainability, conflicts with existing design practices and expectations as users were also a psychological hurdle for UX designers. Among them, the dilemma of conflicts between sustainable design directions and existing design practices is similar to the findings of Sánchez Chamorro et al. [70] that designers are constrained by organizational practices when dealing with ethical issues in design such as "dark patterns." They noted that organizations "impose their own agenda" on designers and "make them accept their limitations as a designer" and argued that under these circumstances, in order for design practitioners to engage with these additional issues, it is important for them to adjust the level of responsibility for the evaluation of design outputs, thus eliminating the risk of contending with negative results. They also said that, to achieve this guarantee, the organization needs to review and balance expertise related to the additional topic (in our case, sustainability). We also recognized a need to define the responsibilities and roles of designers within the organization in order to support design practitioners in taking on topics of digital sustainability that are not typically considered in traditional practice. As evidenced by our study's observation, designers are concerned that the reduction in user lock-in, resulting from designing for digital infrastructure energy consumption, would negatively impact the performance of organizations and also designers. The digital capitalist economy, thriving on "engagement," frequently clashes with the environmental costs of this engagement. Designers could be caught in a conflict where the profit-oriented goals of employers or clients restrict their ability to make necessary choices for SID. Bonnie Nardi [57] pointed out that underlying these challenges is the broader problem of capitalism, which remains unaddressed yet is a critical aspect of the difficulties in implementing sustainable practices. While we could question capitalism itself, we propose that exploring and reviewing political and economic alternatives within the current context is important for practical implementation. To further this point, it is essential to identify and deploy strategies that facilitate the incorporation of sustainable practices within capitalist frameworks. One practical method we suggest is to leverage ESG (Environmental, Social, and Governance) reports, which are periodically required for corporations. By prominently featuring and assessing design initiatives for digital sustainability in their reports, corporations can go beyond simply fulfilling environmental responsibilities and actively recognize these efforts as key performance indicators, thereby encouraging more vigorous sustainable practices. Furthermore, we emphasize that the formation of a consciousness and culture where it is considered valuable and trendy to view such sustainability considerations can help to resolve psychological conflicts among designers. This aligns with previous studies and discussions on the need to establish a culture that recognizes and pursues digital sustainability as important at regulatory and societal levels [11, 19]. These trends and the formation of a culture may play a role in recognizing that adopting sustainable design is not just about being environmentally responsible but is a way to incorporate creativity and innovation in design.

6 LIMITATION AND FUTURE WORK

Our participants did not include individuals with a high interest in the environment or prior knowledge about the digital carbon footprint, which may prevent us from fully understanding the perspectives of the broader group of UX designers. Further studies targeting designers who already practice sustainable actions in their daily lives or have expertise in sustainability could offer deeper discussions and further exploration. Furthermore, in our design workshops, it was revealed that UX designers' technical knowledge, which enables them to understand and hypothesize the development methods of specific features in digital products, plays a crucial role in their design process for sustainability. We did not investigate the participants' background knowledge in front-end and back-end technologies during the recruitment process, but conducting design workshops with various combinations based on this information could provide additional insights.

Also, all participants in our study were from South Korea. This means that our findings might reflect the digital practices, in-house design culture, and laws and regulations specific to South Korea. As the impact of sustainable UX design could be maximized when implemented in digital services with a large number of users worldwide, further research can be conducted to reveal specific problem situations that reflect the cultures of more diverse countries and companies. Additionally, our study took the form of a one-time workshop and focused specifically on the initial ideation stage. Thus, generalizing our findings to the entire design process is challenging. In reality, when sustainability is added as another design goal in a company's design process, designers might face challenges that are much more diverse and complex than what we identified in our research. Targeting design phases other than the ideation stage to

examine additional challenges and needs could present meaningful design opportunities.

Lastly, our study specifically addressed the environmental impact of digital infrastructure with a focus only on the energy consumption related to data storage, transmission, and processing. This research scope does not encompass the negative environmental effects caused by physical infrastructure, making it challenging to describe our workshops as covering the full spectrum of digital infrastructure's environmental impacts. Similarly, our workshops did not include aspects of reducing the use of fuels or physical products through SID interventions within digital services. However, these approaches could provide more specific design objectives compared to the broader and complex goal of reducing energy consumption in digital infrastructure. Therefore, we expect that further in-depth exploration of these design interventions could prove to be a particularly valuable contribution to enhancing environmental sustainability through UX design within digital services.

7 CONCLUSION

In an effort to reduce the environmental impact of various digital services that are deeply embedded in our daily lives, several academic and practical approaches have attempted to intervene through design within digital services. However, understanding the opportunities for more UX designers to engage with design approaches for sustainability (especially in terms of carbon footprint from digital infrastructure energy) and their experiences has not been explored in depth. This study examined UX designers' initial experiences exploring design ideas within digital services toward reducing energy consumption in digital infrastructures. Through a design workshop and debriefing interviews, we focused on identifying designers' perceptions of design for sustainability and the various challenges they face when ideating sustainable design features for existing digital services. In terms of UX designers' early perception, our results show that UX designers new to designing for sustainability perceive this approach as challenging beyond their conventional UX expertise and that the brief experience of this approach could lead them to interpret it as an area where their UX expertise can be accessible, valuable, and essential. Along with UX designers' perspectives toward sustainable design, various confusions and conflicts were discovered that should be understood to support the perceived value of designing for sustainability. These include challenges such as the broad scope and complex nature of sustainability complicating initial engagements and focus, a lack of technical and environmental knowledge necessary for decision-making in good sustainable interaction design, and tensions between corporate profits, user expectations, and sustainability. With the understanding of UX designers' initial perceptions and difficulties within the sustainable design approach, this paper presents insights into UX designers' attempts at sustainable interaction design in digital services and suggests ways to overcome or mitigate their challenges. We hope that our findings and implications will provide a general understanding and inspiration to encourage and effectively support more general UX designers' consideration of digital sustainability aspects in their design process. Furthermore, we hope that this study will motivate more researchers to actively participate in the HCI community's efforts toward UX for digital sustainability.

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A WORKSHOP MATERIALS

This appendix details the materials utilized in the design workshop of our study. The content was developed by the first and second authors, drawing on knowledge and suggestions from prior research on sustainable design [8, 11, 21, 24, 28, 36, 39, 48, 51, 65, 66, 76, 82]. All materials were originally developed in Korean by the authors and used in the workshop, and the content presented here has been translated back into English for reporting purposes. The materials

are organized into three distinct categories, each presented as a one-page document:

- **User Tendencies Toward Sustainable Design**: outlines how users typically respond to and interact with sustainable design elements (Table 3).
- **Implications for Digital Sustainable Design**: discusses the important considerations and suggestions for acceptable and effective sustainable practices in digital design (Table 4).
- **Examples of Digital Sustainable Design**: provides specific instances and recommendations for incorporating sustainability into digital services (Table 5).

Table 3: Document 1 - User tendencies toward sustainable design

No.	User tendencies toward sustainable design	Reference
1	**Users tend to reject changes that require significant sacrifices compared to their existing habits.**	[28], [21]
	- Sol 1. Ensure that the new design does not degrade the existing experience so that users do not have to compromise.	[76]
	- Sol 2. Emphasize the ease of use of the new solution particularly in communications.	[21]
	- Sol 3. Encourage users to start with actions they are willing to accept and try.	[39]
2	**If the new sustainable alternatives do not interfere with existing usage goals and offer a similar user experience without loss of functionality, users are likely to accept them.**	[28], [21]
3	**Even users with the willingness to engage in more environmentally friendly actions often find it difficult because they do not know specifically what they should do.**	[66]
	- Sol 1. Provide information and recommendations on what actions are environmentally friendly.	[66], [39]
4	**Users lack knowledge about the environmental impact of their invisible digital consumption.**	[21], [28], [66]
	- Sol 1. Provide users with knowledge about the environmental impact of digital usage, avoiding overly excessive approaches.	[39]
	- Sol 2. Provide education on the environmental impact of digital usage.	[28], [66]
	- Sol 3. Make sure users understand that individual digital environmentally friendly actions are sufficiently important and effective.	[66]
	- Sol 4. Remind users in real-time that their current behavior is not environmentally friendly.	[39]
5	**Users tend to reduce their energy consumption when they know their energy usage is being monitored by someone else.**	[24]
6	**Users become indifferent to data feedback if they think they cannot change their existing habitual behaviors.**	[82]
7	**Consumers expect companies to fulfill their responsibilities for digital sustainability.**	[21]
	- Sol 1. Inform users about the environmental efforts being made at the corporate level.	[21], [66]

Table 4: Document 2 - Implications for digital sustainable design

No.	Implications for digital sustainable design	Reference
1	**New design proposals require thorough consideration of existing user behaviors, motivations, drivers, and contexts to be acceptable to them.**	[82], [28]
2	**A variety of approaches are needed to effectively mainstream awareness of sustainable practices.**	-
	- Sol 1. Cultivate the perception that sustainable actions are a 'social norm' everyone should follow - encourage the mindset, "If many people consider this important, so should I."	[39]
	- Sol 2. Increase media coverage of digital carbon footprints to make it more well-known.	[28]
	- Sol 3. Enable and encourage people to exchange practical information, experiences, and insights on environmental practices with each other.	[82], [39]
3	**When providing new solutions, the environmental benefits of the feature should be clearly communicated.**	[21]
4	**Various approaches are needed to enable users to have agency in their actions.**	-
	- Sol 1. Support users in setting their own specific and quantitative environmental action goals.	[39], [51]
	- Sol 2. Allow users to manage and control their own environmentally friendly actions.	[21], [51]
	- Sol 3. Help users learn the best methods of action on their own.	[82]
	- Sol 4. Encourage users to reflect on their actions and reconsider the significance of sustainability in their lives.	[39], [11]
5	**Users should be provided with information to monitor their app usage patterns, consumption, energy usage, and environmental impact (eco-feedback).**	[51], [65], [28], [66]
	- Sol 1. Visualize the energy consumption and environmental impact of individual actions to inform users.	[21], [82], [8], [28], [66]
	- Sol 2. Ensure that feedback does not induce additional mental demands, effort, or frustration.	[48]
	- Sol 3. Provide feedback that acknowledges and respects each user's personal value system.	[39], [48], [28], [51]
	- Sol 4. Emphasize providing positive feedback.	[21], [39]
6	**The design of digital services should emphasize their material aspects more.**	[8]
	- Ex. Current cloud imagery, evoking fluffy clouds, obscures the material aspects of cloud service, such as servers and cables.	[8]
7	**Facilitating cooperation or competition (comparison) among people for environmental actions can stimulate motivation.**	[36], [66]

Table 5: Document 3 - Examples of digital sustainable design

No.	Examples of digital sustainable design	Reference
1	**Only automate essential tasks rather than everything in bulk** *(e.g., auto-update only recently used apps)*	[51]
2	**Suppress energy consumption when the device is not active** *(e.g., disable WiFi and mobile data when not in use)*	[51]
3	**Process tasks during periods of low network traffic** *(e.g., pre-download user-favorite music for offline listening during off-peak hours)*	[51], [65]
4	**Set low energy consumption features as the default** *(e.g., reduce default streaming resolution)*	[28], [21]
5	**Provide options that allow users to use only necessary features** *(e.g., offer an audio-only option for streaming video content to users who only listen)*	[51]
6	**Equip users to perform desired actions efficiently by offering detailed guidance** *(e.g., reduce unintended content downloads by providing text descriptions, community* ratings, and short videos)	[65]
7	**Apply high-quality, energy-intensive content only where essential** *(e.g., avoid excessive visual interactions in less accessed areas of a webpage)*	[65]