sustainability

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Systematic Review

Expanding the Concept of Sustainable Interaction Design: A Systematic Review

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Abstract: This paper presents a systemic literature review of Sustainable Interaction Design. We use the PRISMA model to guide the review. In the analysis of the identified papers, we identify an emergent and significant shift in the discourse on Sustainable Interaction Design from its original introduction in 2007. The shift in discourse concerns extensions both in the *methodology* as well as the *impact*, which is oddly underexplored. Regarding the methodology, we found that the objectives of sustainability are pursued *by* the concrete features of designed artifacts or *through* the use impact of design and that the design contains a process of learning for all participating parties, captured in the notion of sustainability *in designing*. By complementing this with the pursued impact of social, environmental, and economic sustainability, we point to where the current research tends to cluster, which areas are underexplored, and, thus, where new research agendas are needed. Here, the limited interest in studying how Interaction Design fosters *sustainability while including an economic perspective* stands out. In the concluding parts of this paper, we propose future research trajectories of SID and speculate and discuss opportunities and challenges for future research.

Keywords: systematic literature review; interaction design; human–computer interaction; design research; sustainability

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1. Introduction

1.1. Aim and Research Motivations

In 2007, Eli Blevis introduced the concept of Sustainable Interaction Design (SID) within the field of Human–Computer Interaction (HCI), aiming to prioritize sustainability in Interaction Design (IxD) [1]. Since then, the body of literature on SID has expanded significantly, revealing its complex nature. Despite this evolution, Blevis's framing of SID has not only endured but has also become a cornerstone in both HCI and IxD.

Originating in the 1970s with roots in computer science, HCI played a pivotal role in the emergence of Interaction Design in the 1990s [2]. This chronological lineage underscores HCI's enduring influence on Interaction Design. The latter has built upon HCI's foundational principles by placing greater emphasis on user experience, discretionary use, and the holistic design of interactions [3]. Blevis's definition of SID remains significant not only within HCI but also in the broader context of designing interactive technologies [4]. Many contributions to Interaction Design, often citing Blevis's original definition, come from scholars with a strong HCI background. This connection also extends to Interaction Design education, where Blevis's SID framework serves as a foundational element.

Given the evolution of IxD, there is a critical need to reassess and expand the definition of SID to encompass the diverse aspects that define the discipline. This need is especially urgent because Interaction Design prioritizes problem framing to a greater extent than HCI, which has traditionally taken a more solution-oriented approach rooted in computer science [3].

The primary objective of this study is to systematically analyze and map the conceptualization and application of "Sustainable Interaction Design" within scholarly discourse, particularly in relation to the design process and the overarching paradigm of sustainability. This investigation seeks to clarify the nuanced dimensions and theoretical foundations that scholars use when addressing SID, with the ultimate goal of deepening our understanding of its complex relationships with both design methodology and the broader framework of sustainability.

1.2. Background Knowledge: The Definition of SID

Blevis [1] defined Sustainable Interaction Design as the act of making or informing choices about future ways of being, using sustainability as a lens to evaluate design values, methods, and artifacts. He specifically emphasized environmental sustainability, highlighting the impact of interactive technologies on resource usage, and provided a rubric for assessing material effects in terms of use, reuse, and disposal.

Blevis's approach inspired a group of academics to organize a workshop during the 2009 Conference on Human Factors in Computing Systems (CHI), where they aimed to define the role HCI could play in addressing the challenges of sustainable development [5]. Their focus began to extend beyond the environmental impacts of complex issues like climate change, seeking to engage professionals from various fields, including design, politics, economics, social studies, and engineering. They also recognized that Sustainable Interaction Design might involve various trade-offs that require careful consideration.

Although Blevis chose to focus on environmental sustainability, in his seminal paper, he referenced Fry's broader concept of sustainability as a vision of viable futures encompassing environmental concerns, public health, social equality and justice, and other factors affecting humanity and the biosphere [6]. This reference indirectly highlighted the multifaceted nature of sustainability, which spans multiple areas and dimensions.

Over time, the term "sustainability" has taken on an increasingly broad and ambiguous meaning. Despite efforts in subsequent years to introduce new perspectives and reconfigure the conceptual framework of SID [7] or to extend its applicability to emerging domains like digital services [8], a dominant trend persisted among scholars engaged in SID research. The community continued to prioritize environmental sustainability, particularly in relation to interactive technologies. This prevailing academic focus reflected an ongoing adherence to Blevis's foundational definition of SID, emphasizing the "ecological" aspects of interactive technologies within the expanding discourse on Sustainable Interaction Design.

1.3. Existing Literature Reviews

In addition to the literature survey presented in this paper, we have also taken stock of existing reviews related to Sustainable Human–Computer Interaction (SHCI) and SID.

The first notable review of SHCI, titled "Three Environmental Discourses in Human-Computer Interaction" by Goodman [9], addresses environmental issues by identifying three key themes—Sustainable Interaction Design, Citizen Sensing, and Revisioning Consumption—that significantly influenced the design of novel interfaces and interactive systems. A year later, another survey, "Mapping the Landscape of Sustainable HCI" [10], analyzed sixty contributions, outlining the development of SHCI as a research field and its various branches. This survey categorized emerging clusters or "genres", including SID, Formative User Studies, Pervasive and Participatory Sensing, Persuasive Technology, and Ambient Awareness. Building on the work of DiSalvo and colleagues, Knowles and colleagues [11] introduced an alternative framework to the seminal "triple bottom line" concept, proposing a "quadruple bottom line" (personal, social, environmental, and economic). In their paper "Exploring Sustainability Research in Computing: Where We Are and Where We Go Next", they pose ten key questions to guide the research agenda for sustainability in computing.

However, "A Systematic Review of Sustainability and Aspects of Human-Computer Interaction" [12] represents the first systematic review in SID. It categorizes fifty contribu-

tions into five distinct areas of focus related to SHCI: persuasion, sustainability in design, design for sustainability, implications for design, and living with technology, along with other specific topics. The review notably highlights climate change and energy conservation as extensively researched areas.

These initial four reviews of sustainability in HCI were subjected to a meta study by Hansson and colleagues [13], titled "A Decade of Sustainable HCI: Connecting SHCI to the SDGs". The study analyzed the four previous literature reviews and then evaluated contributions to SHCI based on their thematic areas, specifically using the Sustainable Development Goals (SDGs) as an external framework to assess the field.

These perspectives are further refined by several studies that adopt a more qualitative approach to analyzing the landscape of SID. First, in 2017, Nunes and Mont'Alvão [14] presented a collection of perspectives and offered a general reflection on possible ways to view the relationship between design, technology, and sustainability, drawing on insights from various review papers. Next, the study "A Digital Nexus: Sustainable HCI and Domestic Resource Consumption" by Green and colleagues [15] is noteworthy as the first one to incorporate social sciences into the discussion of human resource consumption in relation to HCI. The paper examines the implications of digital technology design, particularly in urban contexts, on human resource consumption and its impact on environmental challenges. Additionally, the review "Have We Taken on Too Much? A Critical Review of the Sustainable HCI Landscape" by Bremer and colleagues [16] offers significant critiques of SID as a research field. The authors also propose "calls for action" within Sustainable HCI, introducing a potential solution termed "Green Policy Informatics".

More recently, two systematic literature reviews were published: "Hitting the Triple Bottom Line: Widening the HCI Approach to Sustainability" [17] and "A survey of empirical studies on persuasive technologies to promote sustainable living" [18]. The first review classifies peer-reviewed papers on Sustainable HCI, rather than SID, according to the three sustainability "lines"—environmental, social, and economic—highlighting the need for a more holistic investigation of the often-overlooked economic and social aspects in Sustainable HCI research. The second review systematically analyzes papers related to SID, focusing specifically on those involving persuasive technologies aimed at promoting sustainable living. The authors maintain a narrow focus by defining strict inclusion criteria, ultimately examining a limited set of 15 papers to categorize different approaches to interactive technologies in this context.

These surveys are particularly interesting because they explore the values and concerns embedded in the design of interactive systems and how these systems promote sustainability in diverse ways. However, none of the surveys have addressed the specific ways—or, in Blevis's terms, "senses of design"—in which sustainability is promoted. In this regard, our study seeks to utilize a larger and more recent set of publications to examine how the role of design has evolved in creating interactive solutions to address sustainability issues, considering how the concept of sustainability itself has been articulated by scholars.

1.4. Key Research Elements and Structure

In this paper, we present a systematic literature review of Sustainable Interaction Design (SID) research, including publications up to 2023. We analyze the identified papers through the lens of sustainability, focusing on the concerns originally proposed by Braungart and McDonoug [19]—environment, economy, and social equity—which were reiterated in Scuri and colleagues' study [17]. We then examine how the act of designing promotes sustainability, extending the original two strands for Sustainable HCI (SHCI) proposed by Mankoff, Blevis, and colleagues [20], where sustainability is achieved "*in and through design*".

Through our analysis, we suggest that sustainability relates to (1) the designed artifact (*sustainability by design*), (2) is influenced by the artifact (*sustainability through design*), or (3) is fostered within the design process itself (*sustainability in designing*)—the three definitions are presented at the end of Section 3.2. Our findings indicate that the field of research

tends to favor certain approaches to exploring and promoting sustainability in the design of interactive technologies. Following this, we highlight prominent and emerging themes in SID.

This study concludes by identifying four recurring and five emerging research themes. The paper is structured as follows: In Section 2, we present the methodology of the literature review. In Section 3, we argue in favor of extending Blevis's original two strands regarding how Interaction Design contributes to sustainability. This is followed by an analysis that connects these perspectives and identifies current gaps in the SID literature. Finally, we conclude the paper by discussing the limitations of this study and the potential implications of these gaps for the field's understanding of sustainability.

2. Methodology of the Literature Review

2.1. Scoping Literature Review

This study is based on an initial scoping review of the literature, employing an exploratory approach to review [21]. This review focused on the most relevant publications associated with the keywords "Sustainable Interaction Design" and "SID", as identified in the Scopus and Web of Science databases. The investigation served two main purposes.

First, it aimed to provide a comprehensive understanding of the overall nature of SID, highlighting the key definitions and manifestations that have shaped the research landscape.

Second, by analyzing key papers, we sought to refine and inform the subsequent systematic review, specifically defining the codes to be used during the analysis of full-text publications.

2.2. Systematic Literature Review

The current study employs a systematic literature review [22]. An initial search using Title, Abstract, and Keywords yielded 469 results, published between 2000 and December 2023, related to interaction, design, and sustainability. After excluding duplicates across repositories, the final set of studies included 352 publications. Following the guidelines of the PRISMA model [23] (see Supplementary Materials), we conducted a qualitative screening of abstracts and full papers to identify studies that consistently referenced the definition of SID [1] as outlined in the introduction and aligned with this study's scope. The selected publications were then coded for a more precise mapping of the literature.

2.2.1. Search Keywords and Query Limits

The search strategy involved using various terms related to "Sustainable Interaction Design" to ensure that key definitions, including common alternatives such as "Sustainable Human–Computer Interaction" and their abbreviations, were covered. So, the following resulting initial query was used:

> *TITLE-ABS-KEY ("sustainable interaction design" OR "sustainable HCI" OR "sustainable human computer interaction" OR "SHCI" OR "SID")*

It displayed an initial number of results equal to 352, combining both databases.

In the advanced query search, we deliberately chose not to apply additional filters such as subject area, language, or document type. This decision was based on three main considerations. First, the specificity of the chosen keywords, especially after confirming the correct use of "HCI" and "SID" acronyms, was considered comprehensive enough to capture the relevant literature. Second, the number of results obtained after keyword filtration was manageable, allowing for a thorough review of all 352 publications without compromising this study's depth and timeliness. Third, our focus was on understanding the contextual usage of the "SID" term and definition across various documents. A broad-spectrum approach, rather than an approach limited by specific subjects, languages, or document types, was deemed necessary for a nuanced exploration of SID's application across different contexts and research typologies.

2.2.2. Inclusion and Exclusion Criteria for Abstract Screening

The exclusion criteria were defined during the initial phase of screening titles and abstracts. We aimed to include only those publications that explicitly referred to "Sustainable Interaction Design" in their abstracts or demonstrated a clear focus on prioritizing and integrating sustainability within the context of Digital and Interaction Design. To achieve such a goal, five main criteria of exclusion (EC) targeted in the Title–Abstract–Keyword analysis were defined:

EC 1. The acronyms "SHCI" or "SID" had different meanings from "Sustainable Human–Computer Interaction" and "Sustainable Interaction Design".
EC 2. Sustainability was not the main topic. Instead, it was used as an example of concern for discussing something else.
EC 3. The title or abstract subject was not related to the field of HCI or IxD. Some examples were finance, medicine, and chemistry.
EC 4. The search keyword was included in the authors' keywords but was not present in the abstract or title as it was not the focus of the publication, or it had been misused for the starting definition considered.
EC 5. The record was just the introductory paragraph to a conference proceeding.

Following the first screening of the abstract, 139 papers out of the 352 were excluded, leaving 213 results for the following review stages.

2.2.3. Guidelines for Paper Screening

The full-text screening involved selecting eligible papers and finalizing those to be included in the systematic literature review. During this phase, the primary objective was to include papers where "Sustainable Interaction Design" was clearly and extensively defined and where the relationship between sustainability and Interaction Design was explicitly articulated. To ensure consistency and relevance, three additional qualitative exclusion criteria were formulated, as follows:

EC 6. Publications affirming the overall importance of focusing on sustainability—broadly speaking—in IxD or presenting all the different perspectives in general terms.
EC 7. Summaries of conferences' workshops stating that they will debate about SID in general terms without anticipating an initial position/an interpretation about it.
EC 8. Studies mainly vertical on specific issues that are not strictly related to SID but imply it just as context (e.g., digital art on climate change, ICT for brand sustainability, food science as a lens for examining practices, the problem of engaging academic stakeholders, etc.)

Following this final screening, 28 papers were excluded from the initial set of 213, leaving 185 studies for inclusion in the research (see Appendix A). Among the excluded papers, two could not be analyzed due to restricted access and unavailability, even upon request. The remaining eligible publications were subjected to qualitative analysis through text coding, as detailed in the following section. This process was then visualized using the PRISMA model (Figure 1).

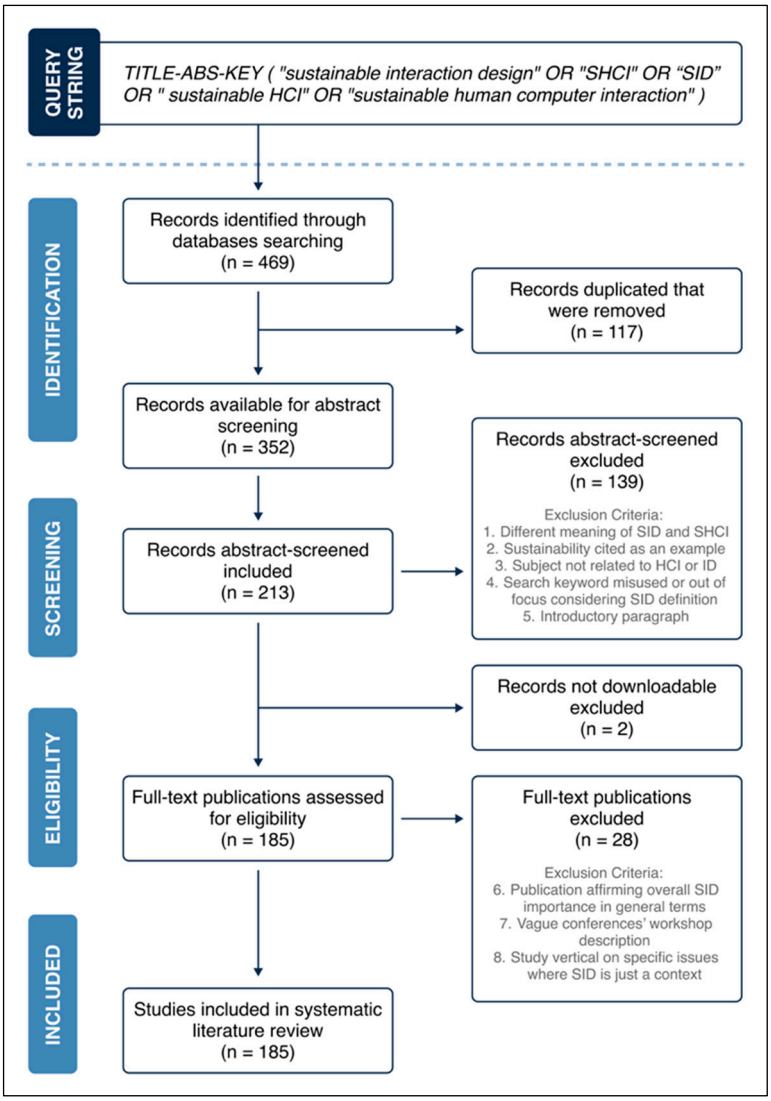

Figure 1. Study's PRISMA model.

3. Sustainable Interaction Design

In this section, we explore the ongoing debate regarding the concept of sustainability in HCI and IxD. We also discuss how our analysis of the identified papers has led to a re-evaluation of Blevis's original framework, which distinguished between *sustainability in design* and *sustainability through design* in Interaction Design.

3.1. Defining Sustainability (in Interaction Design): The Debate

In the following sections, we explore the evolving debate on sustainability in Human–Computer Interaction (HCI) since Blevis's seminal work in 2007. Despite efforts to clarify the concept, sustainability remains a contested and multifaceted issue within SID.

In Sustainable Interaction Design, scholars often refer to the original tripartite classification of sustainability—encompassing environmental, social, and economic concerns—as outlined in the so-called Brundtland report by the UN's World Commission on Environment and Development [24]. However, even foundational works, including Blevis's, predominantly focus on the "environmental" dimension of sustainability [25]. We speculate that this prevailing focus could, among other reasons, be attributed to the initial association of such works with the domains of computer science as initially, the first objective of Sustainable HCI, which was intended to be Sustainable Computing, was to decrease the ecological-footprint of computing itself [26]. This focus differs from the broader scope of

Interaction Design, which tends to incorporate additional considerations, such as social aspects, going beyond technical and computational aspects [3].

A study by Kirchherr and colleagues [27] identified a growing consensus among scholars that "sustainable development" should aim to achieve environmental quality, economic prosperity, and social equity. This reflects a shift toward a holistic perspective that advocates for the simultaneous advancement of all three sustainability dimensions. Other researchers, aligning with the Brundtland Report, define sustainability as meeting current environmental, social, and economic needs without compromising the ability of future generations to meet their own [11], particularly in the context of designing digital interactions and technological interventions.

Scuri and colleagues conducted a systematic review of the HCI literature and found a predominant focus on environmental sustainability in most studies [17]. They emphasized the potential benefits of considering all three dimensions of sustainability, advocating for a more comprehensive definition and deeper integration of these dimensions into the design process.

In light of the prevalent focus on environmental sustainability, some scholars argue for a redirection of SID to address climate change specifically, suggesting that a broader approach to all facets of sustainability might limit the field's contribution [28]. Conversely, other studies acknowledge that while SID may sometimes overreach, establishing a shared, comprehensive understanding of sustainability—encompassing well-defined dimensions, objectives, and metrics—is crucial [16]. These studies also consider non-environmental concerns, such as social and economic growth.

Despite differing opinions on whether to redefine sustainability in Interaction Design or focus on a single dimension, there is a growing recognition of the need for an inclusive approach that addresses all aspects of sustainability [29], including communal and social aspects. Ignoring community reactions when designing environmentally sustainable interventions can lead to social issues, diminishing social cohesion and making such interventions socially unsustainable [30]. Additionally, there is increasing acknowledgment of the importance of incorporating the economic dimension, especially in the development of digital interactive products and services. Mann and Bates, for example, have criticized the lack of engagement in HCI for promoting socio-economic transformation [31]. Blevis and colleagues also noted the need for an in-depth exploration of economic challenges, particularly in guiding design solutions related to digital artifacts [25]. They highlighted the economic dimension as a critical area for research.

In summary, there is a growing consensus in SID that addressing all three dimensions—(i) environmental (quality), (ii) social (equity), and (iii) economic (prosperity)—is essential for developing effective Sustainable Interaction Design solutions [24,27].

Lastly, recent proposals include adopting a value-driven approach in SID [32] and integrating Sustainable Development Goals (SDGs) into the SID definition to place them at the core of the Interaction Design process [13,33]. These approaches aim to make SID more practical and effective, emphasizing the importance of a streamlined definition to help interaction designers center sustainability in their work.

3.2. Mankoff and Blevis's Delineation of SID

Having reviewed the general understanding and promotion of sustainability, we now focus on Blevis's contributions, which are pivotal in the field. Specifically, we draw from Blevis's seminal work with Mankoff and colleagues [20], which provides foundational reference points in Sustainable Interaction Design (SID). In their influential paper, Blevis and his co-authors outline two primary approaches for integrating sustainability into Interaction Design: (i) using sustainability as a guiding principle for the design of interactive systems and (ii) leveraging interactive technologies to promote sustainable behaviors. These approaches are categorized as "*sustainability in design*" and "*sustainability through design*":

1. *Sustainability in design*: This approach involves using sustainability as a critical lens during the design process of interactive technologies. It encompasses four core

dimensions that guide the development of sustainable interactive concepts and artifacts. These dimensions focus on improving energy efficiency, reusing energy, reducing energy consumption, and recycling energy resources. Essentially, this approach treats sustainability as an integrated aspect of the artifact's design—a sustainability by-product.

2. *Sustainability through design*: This approach uses interactive technologies to encourage sustainable behaviors. It emphasizes designing interactions that foster sustainable actions and raise awareness. The resulting technologies can operate at three levels: individual, group, and societal. Here, to our understanding, sustainability is primarily pursued through behavioral change, aiming to influence the mindset and decisions of users to support sustainable lifestyles and decision-making.

Even when critiquing Mankoff and colleagues' 2007 framework, most scholars, including those in the Digital and Interaction Design field, continue to reference and rely on these initial conceptualizations as foundational guidance. This enduring influence has characterized the two critical dimensions proposed, intricately tied to defining the design process for "sustainable" interactive technologies. In our understanding, the two approaches to SID are related to the design process and its phases in two distinct ways:

1. The first approach, "*in design*", comes into play in the phases of a design process in which the essence of design artifacts is shaped. It refers to when designers conceptualize and define the character and features of an interactive artifact (e.g., "an artifact that self-regulates to save energy").
2. In contrast, the second approach, "*through design*", guides designers' concerns in the design processes about how people will interact with the artifact and how the interaction will affect other decisions. It refers mainly to the design considerations in which the objective and scope are developed (e.g., "an artifact persuading people to consume less energy at home").

The separate presence of these two dimensions is proof that design can play different "roles" in putting sustainability at the center when it comes to interactive technologies. At the same time, it leads us to wonder how researchers—since these foundational SID guidelines were formulated—have subsequently approached investigations from distinct perspectives regarding the overall design process.

Redefining the Notion of "Designing" in SID

In this section, we examine how the role of design has evolved and argue that this evolution has led to a redefinition of Sustainable Interaction Design (SID).

Early contributions to the field closely followed Mankoff and colleagues' bipartite framework, which distinguished between "sustainability in design" and "sustainability through design". However, as the body of work has grown, it has become increasingly challenging to classify contributions solely within these two original dimensions. Our exploration reveals numerous studies that address sustainability in ways not confined to these two categories. Some research focuses on methodologies and approaches for achieving sustainability throughout the entire design process rather than just on the inherent sustainability of the artifact or the behavioral impacts of specific interactions. Several notable contributions exemplify this phenomenon.

One of the first examples is a contribution to "sustainable identity" and the creativity of the designer [34], in which the authors discuss incorporating Design-in-Use principles, which involve using sociotechnical and cooperative design methods to create ethically sustainable systems through participatory user involvement. The authors argue that designers should not only apply SID principles but also engage with end-users to understand the ongoing life and potential sustainability of the design artifacts. They suggest that user creativity contributes to a sustainable identity and view unpredictability as a positive trait rather than a challenge.

Another noteworthy example is the study by Heitlinger and colleagues, "Sustainable HCI for Grassroots Urban Food-Growing Communities" [35], which explored how partici-

patory design can be employed to achieve socio-environmental impacts within the context of SID. The authors argue that this approach shifts the focus from viewing individuals merely as consumers to seeing sustainability as a communal concern requiring coordinated collective action. They advocate for participatory design that strengthens connections between collective action, participation, and citizenship. Additionally, Heitlinger and colleagues emphasize designing for inclusion, education, face-to-face communication, and collective engagement, rather than just for efficiency.

A third significant contribution is a study that uses design fiction to explore "green practices" within SID [36]. The authors argue that designers can use resources and tools in ways that address the challenges of making design interventions intelligible in practice. This research suggests that design fiction can reshape sustainable practices and influence the evolution of design itself. The study proposes that design fiction links design with eco-friendly DIY initiatives, routine repairs, and social/cultural theories of practice. By connecting future scenarios with practical and cultural theories, this approach reveals new roles for Interaction Design in promoting environmental sustainability.

Another relevant work is "Constructing and Constraining Participation in Participatory Arts and HCI" [37], which emphasizes the importance of user participation in digital arts and HCI, particularly in enhancing sustainability and understanding social practices. The authors argue that public involvement is crucial for balancing HCI research and suggest that strategies and tactics from social practice arts can be adapted to HCI. This involvement helps designers and users collaboratively shape alternative environmental futures through technology.

The last example of a discourse on methodologies and approaches for achieving sustainability throughout the design process is the contribution to participatory speculative design and experiments with communities in relation to SID [38]. The authors explore how participatory design practices can empower communities to engage more deeply in creating sustainable futures related to climate change. They argue that situated participatory speculation can effectively address potential conflicts that arise when collaboratively developing sociotechnical alternatives. This approach is based on several key beliefs: (i) challenging the normative nature of scenarios, (ii) questioning the traditional role of the researcher, (iii) balancing agency, politics, and deliberation in participatory speculative design, and (iv) embracing community-driven technology visions. The authors also propose practical methods for implementing these principles within communities, fostering a mindset that promotes long-term commitment and contemplation of alternative futures.

These examples highlight a shift in the research field, illustrating that some inquiries now extend beyond the traditional frameworks of "*sustainability in and through design*" in SID. They point to a broader scope of research that includes new methodologies and approaches, emphasizing sustainability throughout the entire design process. In our opinion, such contributions invite a third way or "sense"—as Blevis denotes it in his seminal paper—when articulating the role of design in SID. Furthermore, this helps us acknowledge publications that account for broader considerations of sustainable design practices emphasizing implications, guidelines, and approaches to SID beyond the inherent sustainability of the designed intervention itself. Finally, applying this approach to the role of designing invites discussions on Sustainable Interaction Design processes and methodologies.

To reflect these insights, we propose rephrasing "sustainability in design" as "sustainability by design" to emphasize sustainability as an inherent (by-product) feature integrated into interactive technologies. This modification gives space to the following three ways in which (interaction) design promotes sustainability:

1. *By design*: Signifies that interactive technologies incorporate sustainability into the way they are finally designed, constituting an integral aspect of the artifact or system's design.
2. *Through design*: Denotes that designed interactive technologies function as instruments to propagate sustainable behaviors. Consequently, the positive effects on sustainability are realized through the interaction with technology.

3. *In designing*: Refers to how interactive technologies are conceived, encompassing the design processes and methodologies. Here, sustainability may not be directly instigated by the artifacts or the interactions themselves but instead emanates from the design processes.

4. Mapping the Ways of Promoting SID

In this section, we present three analytical lenses that highlight patterns and similarities in this large corpus of 185 papers [39]. The coding was performed through the Qualitative and Mixed Methods Research program MaxQda. The lenses are as follows:

A. Framing of sustainability: Originally described in the UN Brundtland report [24], echoed in the study by Braungart and McDonaugh [19] and adopted by Scuri et al. [17], it emphasizes that when working toward sustainability, we need to account for environmental, social, and economic concerns. However, as also identified in previous studies, these concerns are not evenly represented and catered for in contributions to Sustainable Interaction Design. The lens is in line with the work contributed by Scuri and associates, but here, we build from a larger and more updated pool of papers.

B. The role of design: As presented in the previous section, Eli Blevis and colleagues [20] put forward that sustainability in Interaction Design could be fostered either "in design"—the artifact in itself conceived and operated in a sustainable fashion, e.g., a product that is fully recyclable, or "through design"—where the design promotes sustainable acts and behavior, e.g., it helps preserve nature. The analytical lens extends Blevis's original approach, and we argue that sustainability is promoted in three ways: *by*, *through*, and *in* design.

C. Recurrent and emerging topics: Finally, we unpack the specific topics and concepts that are repeated multiple times in 185 publications in the corpus (e.g., collapse informatics, persuasive technologies, and e-waste).

The raw numbers were used to yield the distribution of the categories shown in Table 1.

Table 1. Codes for this paper's full qualitative analysis.

A. Framing of Sustainability	B. The Role of Design	C. Recurrent and Emerging Topics
Environmental (179)	Sust. by Design (92)	Behavioral Change (24)
Social (40)	Sust. through Design (99)	Eco-feedback (27)
Economic (8)	Sust. in Designing (76)	Persuasive Technologies (22)
		HCI and Design for Attachment (7)
		HCI Activism and Feminism (5)
		E-Waste (4)
		Permaculture (4)
		Collapse Informatics (4)
		HCI and Bio-materials (3)

4.1. Framing Sustainability

The primary goal of applying the first typology of lenses was to systematically categorize all relevant publications according to the three key dimensions of sustainability: environmental (quality), social (equity), and economic (prosperity).

This methodological approach involved a detailed examination of each publication to assess how sustainability considerations aligned with these three dimensions. Through Lens B, a total of 227 distinct codes were identified, and their distribution and prevalence are illustrated in Figure 2, showing how sustainability concerns are addressed within the analyzed literature.

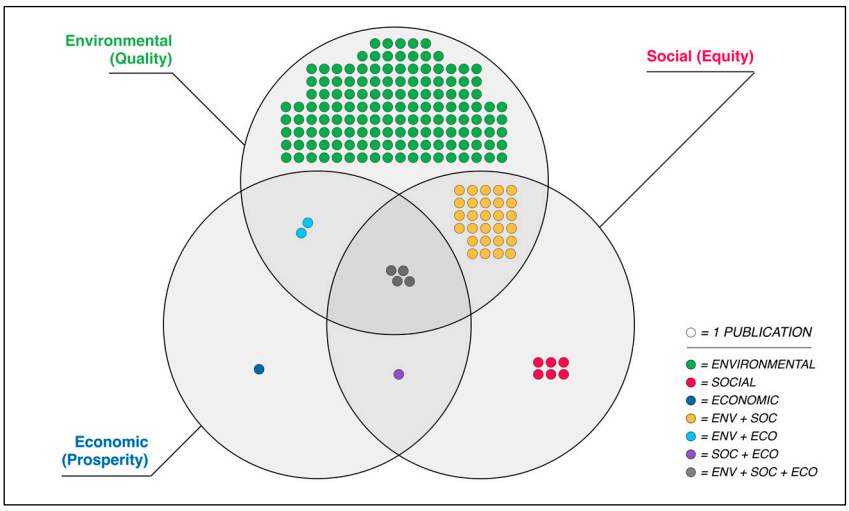

Figure 2. "Framing of Sustainability" code distribution.

From the diagram—which positions each publication according to the sustainable dimensions it covers—it is evident that the distribution among the three categories was significantly imbalanced, and although the included literature is significantly larger than that in the study by Scuri and colleagues [17], the character of distribution of contributions across concerns is well aligned. A significant portion of the literature focuses on environmental sustainability, often overshadowing social equity. Social sustainability was frequently discussed in terms of the "sustainability of a community", typically linked to environmental settings or practices that promote environmental sustainability.

Economic sustainability was the least addressed concern in the papers reviewed. Except for a few publications, discussions on economic sustainability—both political and economic—were notably absent. This highlights a significant gap in addressing prosperity within the context of Sustainable Interaction Design. The only paper that primarily focuses on economic sustainability is the work of Scuri and associates, which explores its role in designing and shaping sustainable economies within Interaction Design.

This analysis confirms the research field bias and the blind spots identified previously and underscores a significant deviation from Blevis's initial conceptualizations of Sustainable Interaction Design, which primarily relate to environmental impact. It also reveals a disconnect between the field of Interaction Design and the broader and more holistic understanding of sustainability promoted by the Brundtland report and various global sustainability initiatives. This gap, previously referred to as "the elephant in the room for Sustainable HCI" [40], aligns with the broader observation that a comprehensive consideration of all three dimensions—environmental, social, and economic—is essential for fostering true sustainable development [27]. We will address this aspect again in Section 5.

4.2. Sustainability by Design and through Design in Designing: The Distribution

Transitioning from the exploration of SID (Sustainable Interaction Design) typologies, our inquiry advanced into understanding how sustainability is integrated within the design process, or "the role of design". To achieve this, we conducted an in-depth analysis of the authors' explicit intentions regarding sustainability within the SID field. This phase, labeled as Code B, involved systematically coding and categorizing all relevant publications according to the refined SID framework: *sustainability by design*, *sustainability through design*, and *sustainability in designing*, as discussed in the previous chapter.

To classify these publications, we meticulously examined each one, focusing on how sustainability was addressed in relation to the design process. This comprehensive analysis led to the identification of 224 distinct codes, with each publication being classified based on its alignment with the identified categories. The distribution of these codes is visually

depicted in Figure 3, illustrating how the various conceptualizations of sustainability are represented within the body of literature under review.

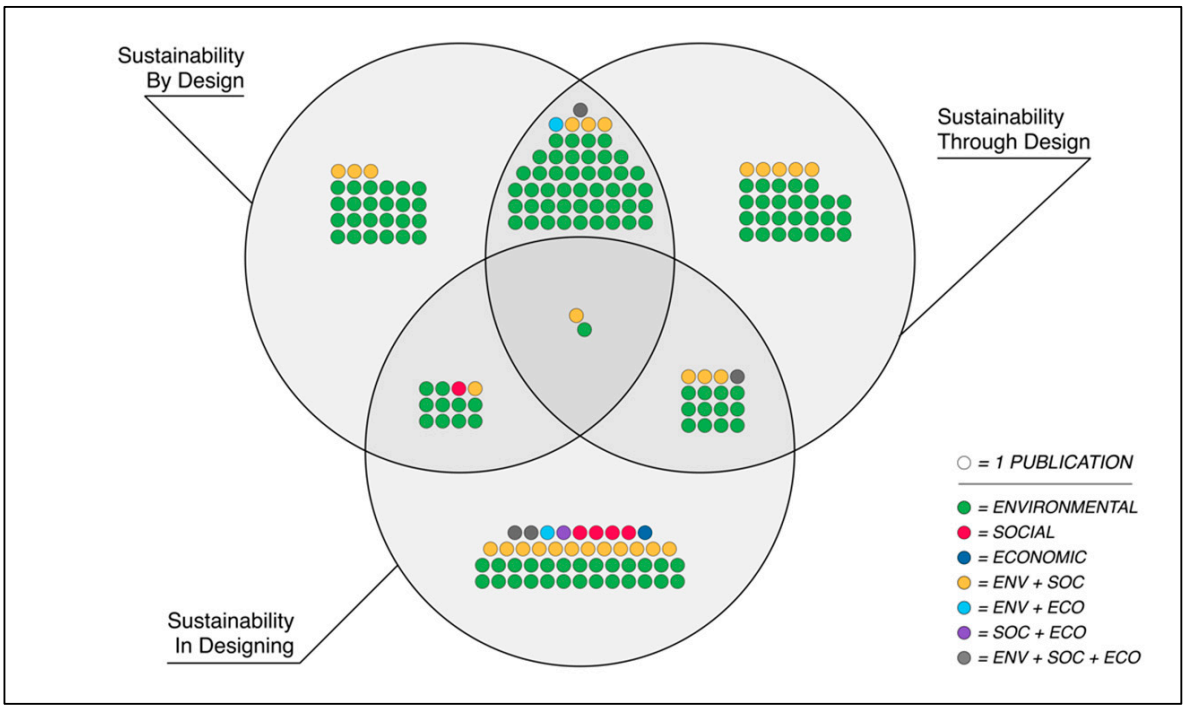

Figure 3. "Role of Design" code distribution.

It is important to note that many publications lacked clear and explicit articulation on this subject. As a result, our approach relied heavily on interpretation, adhering as closely as possible to the predefined definitions of the three categories. To avoid imposing forced categorization, we adopted a careful strategy when faced with ambiguities: instead of rigidly classifying such publications, we assigned them to multiple relevant codes, reflecting the nuanced nature of the interpretative process.

The graph underscores a certain balance across the three categories. Most publications fall within the realms of "sustainability by design" and "sustainability through design", the categories initially identified by Blevis. This distribution suggests a prevalent academic focus on sustainability considerations both in the intrinsic design characteristics of artifacts and in the broader implications arising from user interaction.

An intriguing scenario surfaces within the intersection of these two predominant categories, where a substantial body of research converges. Scholars working within this intersection view SID's interventions as both inherently sustainable in their design and in the consequences of their use—an example being the design of eco-feedback systems that aim to encourage sustainable behavior in users. This dual focus indicates a nuanced understanding of the need to address not only the immediate eco-efficiency of designs but also their long-term ecological impact and the nature of user interactions.

Conversely, only a small portion of the scholarly discourse fully integrates all three dimensions—design for sustainability, sustainability through design, and sustainability in design. The limited representation in this area suggests a potential research gap, indicating that a more holistic exploration of sustainability in interactive technology design might be needed.

However, it is evident that a significant subset of studies is now focusing on the sustainability of the design processes themselves—what we term "sustainability in designing". These studies emphasize designing interactive technologies in ways that are "indirectly sustainable". Here, researchers go beyond assessing the sustainability of the final product, extending their analysis to the methodologies and methods employed in the design process.

This approach acknowledges the multifaceted nature of sustainability, recognizing that the entire trajectory from conception to realization plays a crucial role in determining the sustainable footprint of the resulting interactive technologies.

The investigation affirms the preliminary discovery of the scoping review, highlighting that the field of SID has expanded into more theoretical and overarching topics. The research objectives now extend beyond merely examining the sustainability of artifacts and how we interact with them. This broader focus suggests that SID is evolving into a comprehensive academic discipline that encompasses wider conceptual considerations.

From our perspective, it is increasingly clear that there is a growing need to refine the characterization of SID as a broader approach. This need arises from the observation that many published works do not limit their focus solely to the designed object or its ultimate purpose. Instead, these publications utilize SID as a methodological framework to inform Interaction Design more broadly. This includes applying SID as a lens through which design guidelines, methodologies, and methods—drawn from various design fields—are scrutinized and incorporated into the decision-making processes central to design efforts.

The multifaceted role of SID extends beyond its traditional association with sustainable artifacts and interactions. It plays a crucial role in shaping the broader landscape of Interaction Design, influencing decision-making processes through a detailed examination of diverse design principles. This nuanced perspective underscores the evolving nature of SID, positioning it as an indispensable element of contemporary design scholarship.

4.3. Recurring and Emerging Topics

The third dimension explored in our coded classification focused on the recurring appearance of topics across different publications. This phase took on a more exploratory literature review approach [21], with the aim of identifying recurring trends within the literature. The goal was to pinpoint concepts, theories, and approaches that have significantly shaped the debate around SID in the past, as well as those emerging within the field that extend beyond the typical focus on products or interactions commonly discussed. In our analysis, we identified four main categories of topics that have been recurrent and discussed by several authors since SID was first formulated in 2007. These topics have played a crucial role in shaping the debate around SID and have deep roots in both HCI and design. Our analysis went deeper into these contributions to highlight instances where scholars have offered new perspectives that transcend the traditional boundaries of SID:

- **C1.** Eco-feedback: Eco-feedback technologies, a well-established area within Interaction Design, are widely recognized as mechanisms that provide feedback on individual or group behaviors, with the goal of reducing environmental impact [41]. In the context of SID, most studies associate eco-feedback systems with energy consumption. However, some publications explore aspects like visualization and feedback design independently. Overall, scholars aim to connect energy data with corresponding actions to raise awareness and encourage pro-environmental behavior. This is often interpreted as individual energy conservation in domestic settings, with recent efforts expanding to community-level initiatives [42–44].
- **C2.** Behavioral change: Behavioral change, a prominent concept in HCI and IxD, is primarily defined in most publications as the process of altering attention and cognition to address habitual environmentally harmful behaviors. From this perspective, interactive technologies can motivate individuals toward environmentally friendly behaviors by changing beliefs, shaping attitudes, and influencing actions. The overarching goal is to foster ecological awareness and promote sustainable behaviors. Despite progress, the challenge remains in understanding which interventions, or combinations of interventions, are most effective for specific target users, with the aim of creating a positive and lasting sustainable impact [45,46].
- **C3.** Persuasive technologies: Information and persuasive technologies are often viewed as key tools for promoting behavioral change. In the surveyed literature, persuasive technologies for sustainability typically focus on encouraging self-reflection

in response to shifts in attention and cognition regarding habitual behaviors related to sustainability. Persuasive HCI revolves around designing socially persuasive systems to inspire reflection and behavioral transformation, particularly in promoting sustainable lifestyles within communities. Several scholars argue that values play a significant role in either hindering or facilitating desired behavior change and suggest that integrating value research into persuasive sustainability efforts could lead to more effective interventions [47,48].

- **C4.** HCI and design for attachment: This approach is centered on designing digital artifacts that evoke a deep and lasting sense of attachment in users, with a focus on the emotional connection between the artifact and the user. The challenge is to design artifacts that foster personal meaning, alongside their functional roles. This type of user engagement has been a critical focus in SID research, aimed at reducing material and energy waste [49,50]. Among all these publications, one that is particularly important is the reflection by Pierce and colleagues on designing for "emotional attachment to energy" as a principle within SID [51]. It is important to note that this type of approach to design was already present in other "more traditional designs" when dealing with sustainable implications, for example, in industrial design [52].

Furthermore, some emerging topics have gained attention in recent years, particularly those that extend beyond the traditional definition of SID but are directly connected to it and have implications for the process of designing sustainable interactions:

- **C5.** HCI activism and feminism: The recent literature explores applying activist and feminist approaches in HCI and IxD. This shift moves the focus from individuals—crucial in sustainable HCI, especially regarding behavioral change—to the population as a whole, empowering a broader audience. Design activism requires designers to take greater responsibility, not only in acquiring knowledge but also in introspection and adopting strong stances on their role in fostering positive societal and environmental change. This approach sometimes leverages technology to facilitate collective engagement, such as enabling communication between the public and decision-makers to improve specific situations [53,54]. In contrast, feminist HCI focuses on adopting a feminist methodology of inquiry, with the idea of strengthening interaction designer awareness and a sense of responsibility for the socio-cultural consequences of their proposed interventions and practices [55].
- **C6.** E-waste: On a more practical level, several scholars have focused on e-waste, a concept closely related to designing for attachment. Encouraging personal attachment to electronic devices could prolong their lifespans, helping to prevent e-waste by emphasizing the continuity of digital artifacts' material life after their "death" and narrowing the gap between their functional and perceived lifetimes. Scholars argue that approaching the design process with this perspective could help shift the current disposable technology paradigm. Designing interactive objects with sustainable values could extend their life or, at the very least, promote reflection on disposal, encouraging users to engage with the implications of the waste generated once the object ceases to function [56–58].
- **C7.** Permaculture approach: Recently, some scholars have begun integrating the philosophy of permaculture—an old method of designing sustainable human settlements—into the design process. This approach proposes a methodological shift that promotes harmonious collaboration with nature rather than controlling it, as traditional models often do. Even in crafting fully digital interactions, this perspective advocates for an ecologically conscious approach, drawing inspiration from the sustainable practices of permanent agriculture, even in applications that seem far removed from nature, like UX design for digital artifacts [59,60].
- **C8.** Collapse informatics: Another way of approaching the Interaction Design process that scholars have discussed in recent years is the use of "collapse informatics" as a scenario. It involves guiding design choices by considering the global scarcity of resources, particularly related to informatics and digital artifacts, and how to plan for

a future marked by resource shortages. Scholars in the SID field using this lens argue that researchers should explore how the discipline can help prevent such scenarios or address the challenges that might arise [61,62].

- **C9.** Sustainable HCI and bio-materials: Focusing on the material dimension of SID, some scholars have increasingly emphasized the role of materiality in Interaction Design, specifically in relation to SID. Their studies investigate the sustainability of materials themselves (e.g., using bio-based materials or those that reduce resource consumption and pollution) or the indirect sustainability linked to interactions with the artifact's materiality (e.g., working on sensory experiences, engaging with materiality, or addressing the waste implications). Their research highlights the importance of sustainable materials in extending the lifecycle of interactive objects and reducing environmental impact [63,64].

While these examples represent only a small portion of the concepts that scholars have frequently or recently explored within SID, they serve as indicative snapshots among many contributions coded similarly. These instances highlight the evolving nature of SID, showcasing a diverse array of thoroughly investigated concepts alongside emerging topics that have yet to be fully explored. This blend illustrates the dynamic and expansive landscape of SID, marked by a combination of well-established ideas and promising new avenues for scholarly inquiry.

5. Future Research Trajectories of SID

The presented analysis offers insight into how Interaction Design approaches sustainability and the role that design practices play in shaping a more sustainable future, particularly in the design of technologies and their interactions.

Moreover, by cross-referencing the two main mappings derived from the coding activity, we can identify which areas of SID's proposed new framework are the most extensively explored and which ones hold potential for future research. This is visually represented in the beeswarm chart in Figure 4.

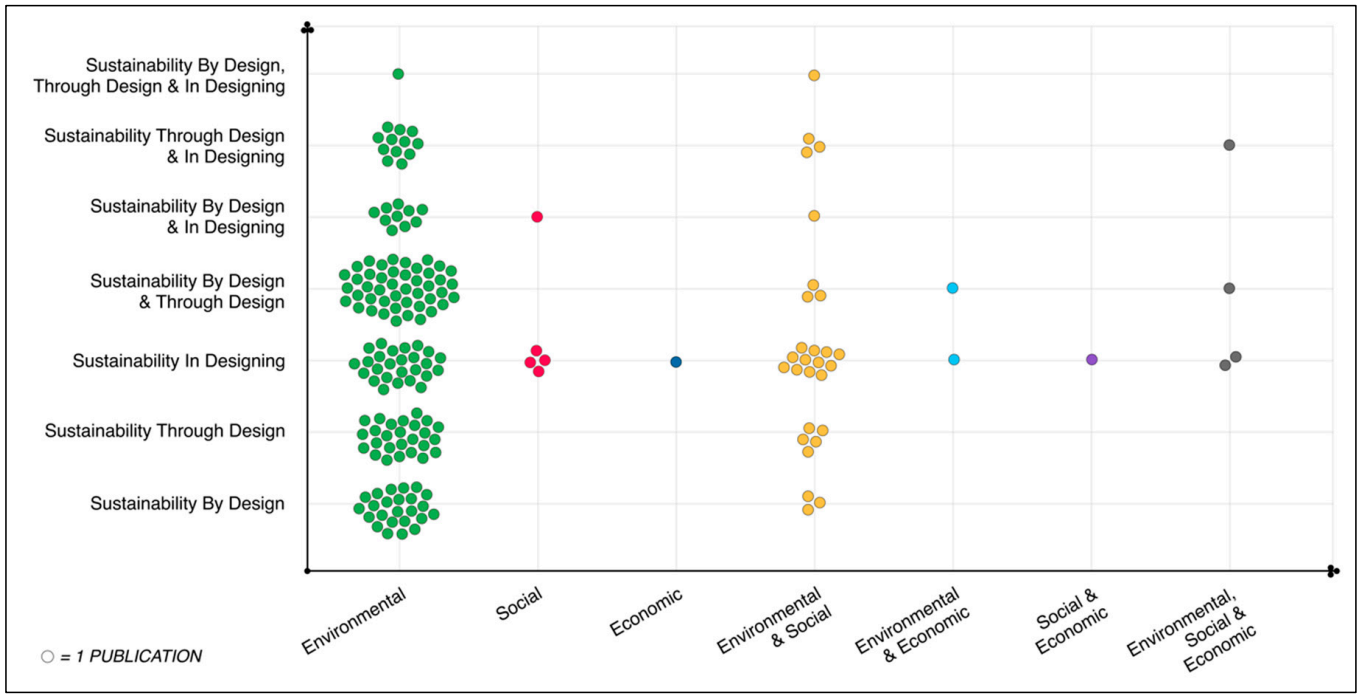

Figure 4. Two-dimensional distribution of contributions.

In line with Scuri and colleagues [17], our study confirms that economic considerations are significantly overlooked in Sustainable Interaction Design (SID) research. While

some scholars do address these considerations within the broader design approach, we emphasize the scarcity of research that directly engages with the economic aspect of sustainability, particularly in the context of designing technologies. Specifically, we observed a lack of contributions that present case studies or interactive technology design processes focusing on the economic dimension of sustainability, resulting in a gap in practical and actionable knowledge.

We infer that this focus may stem from the strong emphasis on environmental issues, as highlighted in the seminal papers by Blevis et al., which are widely cited and referenced in subsequent research. Although later publications by Blevis and others have broadened the definition of sustainability to include a wider range of factors, extending beyond the environmental focus of the Brundtland report, the economic aspect remains underrepresented. This is evident even in the analysis of emerging topics, such as feminist HCI.

The visualizations in our study are intended to illustrate clusters of qualities found in the research papers and the overlaps between these qualities. However, when using a Venn diagram to consider the characteristics of sustainability, as promoted in the Brundtland report—which emphasizes environmental, economic, and social sustainability—there is a risk of fostering an idealized image of contributions, situations, tactics, or strategies. This risk is also present in Figure 2, where it might appear that completing the methodological circle is preferred. We want to clarify that this is not our intention. There may be several reasons for the limited inclusion of all sustainability aspects in publications, such as constraints on paper length, a focus on key findings rather than broader learning, specialized issues in conferences and journal series, and the expertise of reviewers in the field.

While there may be valid reasons for the limited number of publications that comprehensively address all aspects of sustainability, there is still a need for more holistic views on SID. As evident from the first line of Figure 4, there are no comprehensive studies of SID that fully integrate all sustainability dimensions. Furthermore, when the methodological approaches of "by design" and "through design" are combined, the majority of cases focus on environmental sustainability. In contrast, the "in designing" approach appears capable of addressing all aspects and hybrids of SID, although with a continued emphasis on environmental and social sustainability.

Overall, significant portions of Figure 4 are sparsely populated, revealing numerous blind spots and highlighting the many unexplored areas in the design of interactive technologies for sustainability. Finally, we infer that the basic ethos of human-centered design in the field is why contributions tend to cluster around the objectives of improving the environment and empowering those with the agency to act (social sustainability). If we had methods for "capital-centered design" for sustainability, the distribution of research focus in Figure 4 would likely be different.

Study Limitations (and Future Work)

This study is based solely on a systematic literature review, and accordingly, some limitations must be considered. First, the scope of the initial selection of papers may be constrained by the databases used. While we primarily relied on the Scopus and Web of Science databases and made efforts to supplement these with external libraries, some relevant contributions may have been overlooked. Additionally, despite carefully selecting keywords to broadly capture all papers related to the topic, certain publications may have been missed due to differences in how the topic is referenced or how the language is used. However, we believe that our analysis of 352 publications provides a broadly representative sample of the field as it aligns with other literature reviews discussed in Section 1.2.

Second, in terms of methodological considerations, a limitation may be subjectivity in interpretation during the qualitative analysis, which may have influenced the screening and coding of contributions. It is possible that some publications were categorized in a way that does not perfectly align with the selected analysis criteria. Nonetheless, as previously mentioned, the primary objective was to provide a general mapping and overview of the literature and the field as a whole.

Lastly, this study does not address the ethical implications present in the various contributions, which could be a focus for future research. In our analysis, beyond the sustainability debate, ethical considerations were not a chosen lens. At the same time, during the full-text screening, we observed that most papers did not discuss or focus on the ethical implications of Sustainable Interaction Design interventions.

Additionally, we believe that this research can be deepened by integrating it into other fields of research that are both related and unrelated to the design discipline.

For instance, within the design domain, a deeper literature review could be valuable for examining how the three dimensions of sustainability and the three methods by which Interaction Design promotes sustainability are addressed in Service Design—a field that has long engaged in issues like social sustainability. This investigation could reveal how SID can benefit from insights into Service Design and identify if SID-related aspects could be scaled up to create more sustainable interactive services.

Alternatively, moving into other disciplines, one might explore the relationship between SID and the established field of Environmental, Social, and Governance (ESG), particularly concerning the economic aspects of governance. This approach could eventually be valuable to those who wish to move beyond the primary focus of Interaction Design and seek to understand how the proposed frameworks can be integrated at a higher level of society to drive more systematic socio-economic change.

6. Conclusions

This study systematically examines which dimensions of sustainability and their roles within the design process are most emphasized in research related to Sustainable Interaction Design (SID). Through the critical analysis and qualitative interpretation of key contributions over the past two decades, particularly those building on Blevis's foundational work from 2007, we explored this subject.

Our initial literature review identified the 2007 publication by Blevis and colleagues as a seminal guide for Human–Computer Interaction and Digital and Interaction designers in conceptualizing sustainable interactive interventions, specifically within the framework of sustainability "*in and through design*". In line with this framework, we observed that much of the research in this field predominantly emphasizes the environmental dimension of sustainability, often at the expense of the social and economic aspects.

As a result, we outlined the ongoing debate over how scholars in the field define sustainability, using the past literature as a lens. We then explored new methodological approaches for prioritizing sustainability within SID. While most of the reviewed studies initially focused on the creation and development of design artifacts and framed interactions in terms of environmental sustainability, our analysis underscores an emerging need to explore alternative approaches and methodologies developed in recent years. These new approaches aim to guide designers through the entire process of researching and defining digitally interactive solutions that incorporate other dimensions of sustainability, such as social equity and economic prosperity.

By mapping how the three dimensions of sustainability and the three roles of Interaction Design intersect, we identified recurring trends and research gaps within the field. Specifically, our mapping reveals that much of the literature has concentrated on environmental sustainability across all three roles of Interaction Design, but there is still a pressing need to investigate how socio-economic sustainability can be integrated into design practices, both *by design* and within the design process itself.

In this context, this study aims to propose a potential shift toward a more holistic definition of Sustainable Interaction Design or, at the very least, contribute to the ongoing debate within the discipline. In conclusion, regardless of the proposed research trajectory, it may be crucial to find ways to support individuals entering the field in considering the diverse aspects of sustainability at the stages of the design process where a greater emphasis is needed.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su16177486/s1, PRISMA Checklist [65].

Author Contributions: Conceptualization, N.B., P.G.K., M.G.P. and D.S.; methodology, N.B. and D.S.; software, N.B.; validation, P.G.K., M.G.P. and D.S.; formal analysis, N.B. and P.G.K.; investigation, N.B. and P.G.K.; resources, P.G.K., M.G.P. and D.S.; data curation, N.B.; writing—original draft preparation, N.B. and P.G.K.; writing—review and editing, M.G.P. and D.S.; visualization, N.B.; supervision, N.B. and P.G.K.; project administration, N.B. and P.G.K.; funding acquisition, P.G.K., M.G.P. and D.S. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

The following appendix contains a table with all the publications included in the literature review process.

- Yellow = Publication authored and co-authored by Eli Blevis
- Light blue = Contributions included in the book "Digital Technology and Sustainability: Engaging the Paradox" [4]

Table A1. All the publications included in the literature review process.

Title	Authors	Year
Sustainable interaction design: Invention & disposal, renewal & reuse	Blevis E. [1]	2007
Using design critique as research to link sustainability and interactive technologies	Blevis E. et al. [66]	2007
Luxury & new luxury, quality & equality	Blevis E. et al. [67]	2007
Sustainable millennials: Attitudes towards sustainability and the material effects of interactive technologies	Hanks K. et al. [68]	2008
Breaking the disposable technology paradigm: Opportunities for sustainable interaction design for mobile phones	Huang E.M. and Truong K.N. [69]	2008
A bright green perspective on sustainable choices	Woodruff A. et al. [70]	2008
Nourishing the ground for sustainable HCI: Considerations from ecologically engaged art	DiSalvo C. et al. [71]	2009
Three environmental discourses in human-computer interaction	Goodman E. [9]	2009
Human Computer Biosphere Interaction: Towards a Sustainable Society	Kobayashi H. et al. [72]	2009
Understanding why we preserve some things and discard others in the context of interaction design	Odom W. et al. [73]	2009
A sustainable identity: The creativity of an everyday designer	Wakkary R. and Tanenbaum K. [34]	2009
PrintMarmoset: Redesigning the print button for sustainability	Xiao J. and Fan J. [74]	2009
Mapping the landscape of sustainable HCI	Di Salvo C. et al. [10]	2010
Navigating the terrain of sustainable HCI	Di Salvo C. et al. [75]	2010
Making food, producing sustainability	Hirsch T. et al. [76]	2010
Finding the lost treasure: Understanding reuse of used computing devices	Huh J. et al. [77]	2010

Table A1. *Cont.*

Title	Authors	Year
"Mate, we don't need a chip to tell us the soil's dry": Opportunities for designing interactive systems to support urban food production	Odom W. [78]	2010
Designing for emotional attachment to energy	Pierce J. and Paulos E. [79]	2010
Home, habits, and energy: Examining domestic interactions and energy consumption	Pierce J. et al. [51]	2010
Toward an ecological sensibility: Tools for evaluating sustainable HCI	Silberman M.S. et al. [80]	2010
Towards a feminist HCI methodology: Social science, feminism, and HCI	Bardzell S. and Bardzell J. [55]	2011
Social translucence as a theoretical framework for sustainable HCI	Barreto M. et al. [81]	2011
Visible–Actionable–Sustainable: Sustainable interaction design in professional domains	Bonanni L. et al. [82]	2011
Motivating domestic energy conservation through comparative, community-based feedback in mobile and social media	Petkov P. et al. [83]	2011
Engaging energy saving through motivation-specific social comparison	Petkov P. et al. [84]	2011
Designing eco-feedback systems for everyday life	Strengers Y. [44]	2011
My grandfather's iPod: An investigation of emotional attachment to digital and non-digital artefacts	Turner P. and Turner S. [85]	2011
Power to the people: Dynamic energy management through communal cooperation	Boucher A. et al. [86]	2012
Sustainably unpersuaded: How persuasion narrows our vision of sustainability	Brynjarsdóttir H. et al. [87]	2012
Understanding domestic energy consumption through interactive visualisation: A field study	Costanza E. et al. [88]	2012
Inspiring the design of longer-lived electronics through an understanding of personal attachment	Gegenbauer S. and Huang E.M. [49]	2012
Symbolic documentation: Toward fashion-related sustainable design	Pan Y. [89]	2012
Re-conceptualizing fashion in sustainable HCI	Pan Y. et al. [90]	2012
Personalised eco-feedback as a design technique for motivating energy saving behaviour at home	Petkov P. et al. [91]	2012
Evaluating semi-automatic annotation of domestic energy consumption as a memory aid	Richardson D.P. et al. [92]	2012
"we've bin watching you"—Designing for reflection and social persuasion to promote sustainable lifestyles	Thieme A. et al. [48]	2012
Collapse informatics: Augmenting the sustainability & ICT4D discourse in HCI	Tomlinson B. et al. [93]	2012
Domestic artefacts: Sustainability in the context of Indian Middle Class	Vyas D. [94]	2012
Facilitation of sustainability through appropriation-enabling design	Arakelyan A. and Lamas D. [95]	2013
Eco-Buzz: An interactive eco-feedback system based on cultural forms of play	Banerjee A. [96]	2013
Designing beyond habit: Opening space for improved recycling and food waste behaviors through processes of persuasion, social influence and aversive affect.	Comber R. and Thieme A. [45]	2013
Beyond being green: Simple living families and ICT	Håkansson M. and Sengers P. [97]	2013
Design Activism in the HCI Classroom	Hauser S. et al. [53]	2013

Table A1. *Cont.*

Title	Authors	Year
Sustainable HCI for grassroots urban food-growing communities	Heitlinger S. et al. [35]	2013
Living lab and research on sustainability: Practical approaches on sustainable interaction design	Keyson D.V. et al. [98]	2013
Re-Imagining Persuasion: Designing for Self-Transcendence	Knowles B. [47]	2013
Greenify: Fostering Sustainable Communities Via Gamification	Lee J.J. et al. [99]	2013
Introduction to the special issue on practice-oriented approaches to sustainable HCI	Pierce J. et al. [100]	2013
Taking a note from marketing research in sustainable HCI	Remy C. [101]	2013
Collapse informatics and practice: Theory, method, and design	Tomlinson B. et al. [62]	2013
A sustainable design fiction: Green practices	Wakkary R. et al. [36]	2013
Sustainability in the workplace: Nine intervention techniques for behavior change	Yun R. et al. [46]	2013
Ghost Hunter: Parents and children playing together to learn about energy consumption	Banerjee A. and Horn M.S. [102]	2014
Towards an holistic view of the energy and environmental impacts of domestic media and IT	Bates O. et al. [103]	2014
Rewriting, redesigning and reimagining the recipe for more sustainable food systems	Frawley J.K. et al. [104]	2014
The talking plants: An interactive system for grassroots urban food-growing communities	Heitlinger S. et al. [105]	2014
Social practices, households, and design in the smart grid	Katzeff C. and Wangel J. [106]	2014
Rethinking plan A for sustainable HCI	Knowles B. et al. [7]	2014
Patterns of persuasion for sustainability	Knowles B. et al. [107]	2014
Human-computer-biosphere interaction: Beyond human—Centric interaction	Kobayashi H.H. [108]	2014
Designing persuasive systems for sustainability—A cognitive dissonance model	Mustaquim M. and Nyström T. [109]	2014
Open sustainability innovation—A pragmatic standpoint of sustainable HCI	Mustaquim M.M. and Nyström T. [110]	2014
Sustainable information system design and the role of sustainable HCI	Nyström T. and Mustaquim M.M. [111]	2014
Fashion thinking: Lessons from fashion and Sustainable interaction design, concepts and issues	Pan Y. and Blevis E. [112]	2014
Rethinking sustainability in computing: From buzzword to non-negotiable limits	Pargman D. and Raghavan B. [113]	2014
'Sometimes it's the weather's fault'—Sustainable HCI & political activism	Prost S. et al. [54]	2014
Next steps for sustainable HCI	Silberman M.S. et al. [114]	2014
PORTS: An interdisciplinary and systemic approach to studying energy use in the home	Wilson G.T. et al. [115]	2014
Exploring (un)sustainable growth of digital technologies in the home	Bates, O. et al. [116]	2015
Role-based eco-info systems: An organizational theoretical view of sustainable HCI at work	Castelli N. et al. [117]	2015
Sustainability Begins in the Street: A Story of Transition Town Totnes	Gui, X.N. and Nardi, B.N. [118]	2015

Table A1. *Cont.*

Title	Authors	Year
Constructing and constraining participation in participatory arts and HCI	Holmer H.B. et al. [37]	2015
Growing food in the city: Design ideations for urban residential gardeners	Lyle P. et al. [119]	2015
Fashion thinking: Fashion practices and sustainable interaction design	Pan Y. et al. [120]	2015
Understanding limits from a social ecological perspective	Pargman T.C. and Joshi S. [121]	2015
Addressing obsolescence of consumer electronics through sustainable interaction design	Remy C. [122]	2015
Bridging the theory-practice gap: Lessons and challenges of applying the attachment framework for Sustainable HCI design	Remy C. et al. [50]	2015
Addressing the obsolescence of end-user devices: Approaches from the field of sustainable hci	Remy C. and Huang E.M. [123]	2015
Limits and sustainable interaction design: Obsolescence in a future of collapse and resource scarcity	Remy C. and Huang E.M. [61]	2015
Sustainable making? Balancing optimism and criticism in HCI discourse	Roedl D. et al. [29]	2015
What people do with consumption feedback: A long-term living lab study of a home energy management system	Schwartz T. et al. [124]	2015
LightShare: Sharing illumination the tangible way	Tong Y. et al. [125]	2015
Engaging children with nature through environmental HCI	Anggarendra R. and Brereton M. [126]	2016
An analysis of persuasive technologies for energy demand side management	Daniel M. et al. [127]	2016
Challenging the role of design(ing) in the sustainability field—Towards a 'humble' design approach	De Jong A. et al. [128]	2016
SYSTEMATEKS: Scalable interactive modular simulation (SIMS): Towards sustainable design	Ferrara L. and Dadashi N. [129]	2016
InfoPlant: Multimodal augmentation of plants for enhanced human-computer interaction	Hammerschmidt J. et al. [130]	2016
Linking data to action: Designing for amateur energy management	Hasselqvist H. et al. [43]	2016
Challenging the car norm: Opportunities for ICT to support sustainable transportation practices	Hasselqvist H. et al. [131]	2016
HeatDial: Beyond user scheduling in eco-interaction	Jensen R.H. and Hasselqvist H [132]	2016
A sustainable HCI knowledge base in progress	Knowles B. and Håkansson M. [133]	2016
Impoverished visions of sustainability: Encouraging disruption in digital learning environments	Meyers E.M. and Nathan L.P. [134]	2016
Understanding and mitigating the effects of device and cloud service design decisions on the environmental footprint of digital infrastructure	Preist C. and Hasselqvist H [135]	2016
Improving attractiveness of public transportation with interactive experiences	Väänänen K. et al. [136]	2016
Eco-feedback visualization for closing the gap of organic food consumption	Zapico J.L. et al. [137]	2016
Further connecting sustainable interaction design with sustainable digital infrastructure design	Blevis E. et al. [138]	2017
Towards a social practice theory perspective on sustainable HCI research and design	Clear A.K. and Comber R. [139]	2017

Table A1. *Cont.*

Title	Authors	Year
Response 2: Challenging the scope?	Costanza E. [4]	2017
Designing and evaluating ambient tangible interfaces for shifting energy supply in the workplace	Daniel M. [140]	2017
CAIRNS: An ambient tangible interface for shifting energy demand at work	Daniel M. et al. [141]	2017
Reducing children's psychological distance from climate change via eco-feedback technologies	Dillahunt T. et al. [142]	2017
Sustainable HCI: Blending permaculture and user-experience	Egan C. and Benyon D. [143]	2017
Permaculture as a foundation for sustainable interaction design and UX	Egan C. et al. [144]	2017
EcoSonic: Auditory peripheral monitoring of fuel consumption for fuel-efficient driving	Hammerschmidt J. and Hermann T. [145]	2017
Response 3a: Connected and complicit	Hogan M. [57]	2017
Community-empowered air quality monitoring system	Hsu Y.-C. et al. [146]	2017
Every little bit makes little difference: The paradox within SHCI	Joshi S. and Cerratto Pargman T. [4]	2017
Response 3b: From participatory design to participatory governance through sustainable HCI	Kennedy R. [4]	2017
A conversation between two sustainable HCI researchers: The role of HCI in a positive socio-ecological transformation	Mann S. and Bates O. [4]	2017
Developing a political economy perspective for sustainable HCI	Nardi B. and Ekbia H. [40]	2017
Perspectives in sustainable interaction design: A preliminary discussion involving human values and HCI	Nunes L. and Mont'Alvão C. [14]	2017
Response 1a: Sustainable HCI: From individual to system	Preist C. [4]	2017
Means and ends in human-computer interaction: Sustainability through disintermediation	Raghavan B. and Pargman D. [26]	2017
Exploring the flexibility of everyday practices for shifting energy consumption through clockcast	Rasmussen M.K. et al. [147]	2017
The limits of evaluating sustainability	Remy C. et al. [148]	2017
Communicating SHCI research to practitioners and stakeholders	Remy C. and Huang E.M. [4]	2017
Three principles of sustainable interaction design, revisited	Roedl D. et al. [25]	2017
Response 4: Sustainability futures and the future of sustainable HCI	Strengers Y. [4]	2017
A survey of empirical studies on persuasive technologies to promote sustainable living	Agnisarman S. et al. [18]	2018
Building momentum: Scaling up change in community organizations	Biørn-Hansen A. and Håkansson M. [149]	2018
Design-insights for devising persuasive IoT devices for sustainability in the workplace	Casado-Mansilla D. et al. [150]	2018
More-than-human urban futures: Speculative participatory design to avoid ecocidal smart cities	Clarke R. et al. [151]	2018
"Will the Last one out, please turn off the lights": Promoting energy awareness in public areas of office buildings	Coutaz J. et al. [152]	2018
Designing for diverse stakeholder engagement in resource-intensive practices	Hasselqvist H. and Eriksson E. [153]	2018
Visualizing carbon footprint from school meals	Hedin B. et al. [154]	2018
What can you do with 100 kWh? A longitudinal study of using an interactive energy comparison tool to increase energy awareness	Hedin B. and Zapico J.L. [155]	2018

Table A1. *Cont.*

Title	Authors	Year
Avoiding ecocidal smart cities: Participatory design for more-than-human futures	Heitlinger S. et al. [156]	2018
Computer as partner: A critique perspective of interaction design for social sustainability	Ho J.C.F. [30]	2018
Assisted shifting of electricity use: A long-term study of managing residential heating	Jensen R.H. et al. [157]	2018
Washing with the wind: A study of scripting towards sustainability	Jensen R.H. et al. [158]	2018
This changes sustainable HCI	Knowles B. et al. [28]	2018
Out of control: Reframing sustainable HCI using permaculture	Liu S.-Y.C. et al. [60]	2018
Exploring sustainable HCI research through the inclusive innovation framework	Nyström T.; Mustaquim M. [159]	2018
Examining the role visual graph structures play in collective awareness and cooperative decisions	Promann M. [160]	2018
Evaluation beyond usability: Validating sustainable HCI research	Remy C. et al. [161]	2018
"Data justice" by design: Building engagement through civic technologies	Walker D. [162]	2018
The Lions' gate: Towards a permaculture-inspired blended space	Egan C. et al. [59]	2019
The right to the sustainable smart city	Heitlinger S. et al. [163]	2019
Smell Pittsburgh: Community-empowered mobile smell reporting system	Hsu Y.-C. et al. [164]	2019
Designing for multispecies collaboration and cohabitation	Liu S.-Y. [165]	2019
Designing with, through, and for human-nature interaction	Liu S.-Y. [166]	2019
Thermporal: An easy-to-deploy temporal thermographic sensor system to support residential energy audits	Mauriello M.L. et al. [167]	2019
Evaluating sustainable interaction design of digital services: The case of YouTube	Preist C. et al. [8]	2019
Not (B)interested? Using Persuasive Technology to Promote Sustainable Household Recycling Behavior	Bremer C. [168]	2020
A digital nexus: Sustainable HCI and domestic resource consumption	Green N. et al. [15]	2020
Lumen: A Case Study of Designing for Sustainable Energy Communities through Ambient Feedback	Hansen A.H. et al. [169]	2020
Waste Wizard: Exploring Waste Sorting using AI in Public Spaces	Jacobsen R.Mø. et al. [170]	2020
Designing for transitions in rural transport	Karahasanovic A. et al. [171]	2020
Designing for the end of life of IoT objects	Lechelt S. et al. [58]	2020
Econundrum: Visualizing the climate impact of dietary choice through a shared data sculpture	Sauvé K. et al. [172]	2020
Single Use Goes Circular–An ICT Proto-Practice for a Sustainable Circular Economy Future	Junge I.P. [173]	2021
E-Scooter Sustainability—A Clash of Needs, Perspectives, and Experiences	Kjærup M. et al. [174]	2021

Table A1. *Cont.*

Title	Authors	Year
One Byte at a Time: Insights about Meaningful Data for Sustainable Food Consumption Practices	Lindrup M.V.A. et al. [175]	2021
Can hci help increase people's engagement in sustainable development? A case study on energy literacy	Pestana C. et al. [176]	2021
Supporting Interaction with CO_2 as a Resource with Individual Carbon Footprint Trackers as Everyday Assistants	Schrills T. et al. [177]	2021
Envirofy your Shop: Development of a Real-time Tool to Support Eco-friendly Food Purchases Online	Shakeri G. and McCallum C.H. [178]	2021
What We Speculate about When We Speculate about Sustainable HCI	Soden R. et al. [179]	2021
A Tale of Two Mice: Sustainable Electronics Design and Prototyping	Arroyos V. et al. [56]	2022
Designing Smart Plugs for Interactivity and Energy Sustainability via a Survey and Thematic Analysis	Barreto M. et al. [42]	2022
Designing with Alganyl: A Hands-on Exploration of Biodegradable Plastics	Bell F. and Alistar M. [63]	2022
Choosing a Questionnaire Measuring Connectedness to Nature for Human-Computer Interaction User Studies	Bouzekri E. and Rivière G. [180]	2022
Tangibility and Engagement in Environmental Behavior: Toward a Longitudinal Study	Bouzekri E. and Rivière G. [181]	2022
Have We Taken On Too Much?: A Critical Review of the Sustainable HCI Landscape	Bremer C. et al. [16]	2022
Patterns and Opportunities for the Design of Human-Plant Interaction	Chang M. et al. [182]	2022
Negotiating sustainable futures in communities through participatory speculative design and experiments in living	Chopra S. et al. [38]	2022
Aqua: Leveraging Citizen Science to Enhance Whale-Watching Activities and Promote Marine-Biodiversity Awareness	Dionisio M. et al. [183]	2022
Exploring Renewable Energy Futures through Household Energy Resilience	Hasselqvist H. et al. [184]	2022
Exploring Biofoam as a Material for Tangible Interaction	Lazaro Vasquez E.S. et al. [64]	2022
Sustainable Foodtures: Exploring Roles of Future Technology in Sustainable Food Shopping	Lindrup M.V.A. et al. [185]	2022
Between Egoism and Altruism: A Mixed-Methods Study of Reflections about Energy Use in the Life Cycle of High Preference Grocery Products	Lindrup M.V.A. et al. [186]	2022
Phenology Probes: Exploring Human-Nature Relations for Designing Sustainable Futures	Rodgers S. et al. [187]	2022
Noticing the Environment—A Design Ethnography of Urban Farming	Rosén A.P. et al. [188]	2022
Hitting the Triple Bottom Line: Widening the HCI Approach to Sustainability	Scuri S. et al. [17]	2022
Ecorbis: A Data Sculpture of Environmental Behavior in the Home Context	Stegers B. et al. [189]	2022
Designing Interactions with Kombucha SCOBY	Bell F. et al. [190]	2023
A Methodology and a Tool to Support the Sustainable Design of Interactive Systems: Adapting systemic design tools to model complexity in interaction design	Bornes L. [191]	2023

Table A1. *Cont.*

Title	Authors	Year
Validating Design Choices of a Bio-Inspired Histogram to Support a Shared Practice of Clean Energy at the Workplace	Bouzekri E. and Rivière G. [192]	2023
Regulating Responsibility: Environmental Sustainability, Law, and the Platformisation of Waste Management	Comber R. and Rossitto C. [193]	2023
(Re-)Distributional Food Justice: Negotiating conflicting views of fairness within a local grassroots community	Engelbutzeder P. et al. [194]	2023
Value misalignments in interactions: An opportunity for sustainable HCI	Grimal L. et al. [32]	2023
Sustainability by Design. How to Encourage Users to Choose Energy-Saving Programs and Settings when Washing Laundry	Grönewald L. et al. [195]	2023
Exploring Values of Energy Justice: A Case Study of a Burgeoning Energy Community	Jensen V.V. and Jensen R.H. [196]	2023
Sustainable HCI Under Water: Opportunities for Research with Oceans, Coastal Communities, and Marine Systems	Perovich L.J et al. [197]	2023
Pick Me Up Before You Go-Go: Sociotechnical Strategies for Waste in Music Festival Campsites	Vella K. [198]	2023

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