Have We Taken On Too Much?: A Critical Review of the Sustainable HCI Landscape

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ABSTRACT

By CHI 2022, fifteen years will have passed since the emergence of Sustainable HCI (SHCI), which now constitutes an important subfield of HCI. In this paper, we draw on two SHCI corpora to ask: Has SHCI progressed? How has the field responded to prominent critiques? Have we identified and adopted constructive strategies for impacting environmental unsustainability? We further show the wide array of competencies SHCI researchers have been called to develop, and how this has been reflected in subsequent work. Our analysis identifies significant shifts in the SHCI landscape, toward research that is diverse and holistic, but also away from efforts to address the urgent climate crisis. We posit that SHCI has tended to take on far more than it could reasonably expect to deliver, and propose 'Green Policy informatics' as a pathway that enables SHCI to leverage a more traditional HCI skillset in addressing climate change.

CCS CONCEPTS

• **Social and professional topics → Sustainability**; • **Human-centered computing → Human computer interaction (HCI)**.

KEYWORDS

Sustainable HCI, Sustainability, Climate Change, Reflective HCI, Policy

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1 INTRODUCTION

Since two foundational publications were presented at CHI 2007 [9, 58], Sustainable Human-Computer Interaction (SHCI) has grown into an important subfield of HCI. Driven by the aim to limit environmental consequences related to computing technology and to use computing to help effect pro-environmental behaviours, its research is situated at the intersection of technology, its users, and topics like energy, resource consumption and recycling. Despite its young history, SHCI has seen significant critical engagement with its publications, with a number of key critiques emerging that challenge the assumptions of the field. For example, many have called for a move away from designs which effect individual behaviour change, an approach that is deeply ingrained in traditional user-centred HCI research. In their seminal 2010 paper, DiSalvo et al. found that persuasive technology accounted for 45% of their SHCI corpus [22], a popular strategy being the use of eco-feedback technology to provide users with feedback on their resource consumption or other sustainability-related habits like waste disposal [29]. Critics challenged the notion that people are 'rational consumers' capable of engaging with the feedback provided to make more informed choices [84], and also argued that persuasive sustainability interventions tend to overestimate individuals' capacity for action [13]: "even the best designed and most well intended PT [persuasive technology] application to foster sustainable behaviour cannot persuade users to engage in the desired behaviours if the circumstances are not allowing or supporting them." [30]. Other critics questioned the effectiveness of individual behaviour change, for example arguing that, "when evaluated 'in the wild', the scale of reduction achieved tends to be limited to less than 10 percent (of, say, household electricity or water) and is not proven to be long-lasting" [38], and (perhaps more fundamentally) challenged the belief that "by merely changing practices at an individual level one can do away with unsustainability" [46].

Based on these concerns, there were calls to move "beyond persuasion" [66], and in general the community began to wrestle with a deep existential question: *is technology the answer?* Mankoff asked, "What percentage, really, would even global adoption of any of our projects create?" [57], while others more explicitly urged the community to "develop a reflective awareness for situations in which computational technologies may be inappropriate or potentially harmful" [6] and realise that "while there will always remain problems for computer researchers and professionals to solve, not all problems are necessarily best solved by the application of ICT/computing power or 'high-tech' solutions" [65]. The emerging consensus was that SHCI needed to 'study up' in non-HCI to be able to do better HCI—to integrate knowledge from diverse fields, grapple with theory, and expand our skillset before we are able to design appropriate solutions in this space. But this is a practically oriented field: "We want to change things for real, not just write papers," one researcher was quoted as saying [79]. We see this tension between a) the desire and need for impact (urgently!) and b) the calls to shift from well-established, tangible HCI methods towards approaches that are more theoretical and complex as a cause for concern. Can the SHCI community internalise these critiques without stretching

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beyond reasonable competencies of the discipline? How/can SHCI leverage HCI's core strengths to meaningfully contribute towards sustainability *now*?

This paper explores how SHCI has responded over the years to critiques arising from the community, and whether this has opened up fruitful new territory for impactful work. To begin, we summarise a number of key critiques in the field in terms of what they are demanding of HCI researchers. Next, we survey SHCI publications at CHI conferences between 2019 and 2021, comparing the current landscape of SHCI to the one mapped in 2010 [22] in order to reflect on where these critiques have gotten us. Did these critiques open up new vistas? Are we creating radically different kinds of interventions which are more likely to make lasting impact? If not…then what? Our aim is not to judge SHCI contributions as right or wrong, or overtly diminish the wide range of contributions, sensitive engagements, or knowledge and capability of the researchers that make up this community. Rather, this paper aims to provide an overview of the critical reflections on SHCI research and explore the difficulties researchers have faced in enacting the advice entailed in these critiques. Ultimately this paper proposes that there may be a simpler route to follow: one that enables SHCI to leverage a traditional HCI skillset in delivering key impact toward arresting the climate emergency.

2 HISTORICAL CONTEXT

To understand the breadth of skills and knowledge that make up HCI traditionally, and its role in addressing sustainability—as conceived at the inception of SHCI as compared with more recent years—it is important to provide some background on the history of HCI. This includes the various paradigms that have arisen in conjunction with technological innovation, as also discussed in depth by [11, 74].

HCI is a relatively young scientific discipline whose roots can be traced back to human factors engineering and information processing. After the Second World War, computers were still relying on vacuum tubes for logic circuitry, and programs were loaded from tapes rather than by pressing buttons and switches; processes which needed to be optimised for efficiency [32]. As transistors replaced vacuum tubes, prototype building gathered pace and, in 1959, Brian Shackel published the first HCI paper "Ergonomics for a Computer" [75]. What came to follow was the first of three waves that describe key paradigm shifts in the field [24]. During the first wave, researchers aimed to achieve an optimal 'fit' between humans and machines to reduce errors and disruptions. Their research was founded in empiricism and quantitative methodologies; within an objective rhetoric, users were regarded as 'human factors' or calculable elements of human-machine systems. Key technological innovations during the first wave were the advent of mainframe computers and the launch of large-scale data processing projects, which gave rise to methodological innovations like style guides, usability labs and task analysis. The second wave emerged when the arrival of powerful minicomputers and the graphical user interface (GUI) enabled interactive and discretionary use of computers by non-specialists. HCI researchers who were tasked to optimise the new interfaces, started to require an understanding of both the machine and the mind. Drawing from psychology and cognitive science, their focus shifted from the body to the mind, from human factors to human actors [3]. While the research rhetoric remained emotionally neutral, true experimental methods of inquiry were complemented with more qualitative ones. With the growth of communication networks and the full emergence of the web, the third wave began. In response to the spread of mobile phones, web-based tools like blogs and wikis, and social networking, HCI researchers became interested in digitally-mediated communication. Drawing from disciplines like anthropology and sociology, they started to reflect on the social and emotional aspects of these interactions [11]. The rise of ubiquitous computing brought with it another layer of complexity and fundamentally changed the role of computers, which became far more than the cognition aids they used to be. Researchers began to stress previously marginalised matters like culture and values, to study a multitude of contexts outside of the workplace and to add wicked problems, including inequalities and climate change, to the research agenda. The objectivist standpoints of the first and second waves gave way to social-constructivist and phenomenological approaches, which acknowledge the existence of multiple subjective realities, biases, and the researchers' influence over participants.

The waves highlight HCI's interdisciplinary, contextual and increasingly complex nature. Shaped by rapid innovation, HCI needs to account for and support society's changing relationship with technology, which is now omnipresent, pervasive in all areas of life. With the multitude of new contexts that have become relevant to HCI during the third wave, the community has shifted their focus beyond user-machine interactions. Optimistic that technology can help solve the world's big problems, subfields like SHCI emerged. Climate change, however, is rooted outside of computing, and aiming to provide solutions, we have taken on a huge responsibility. Even more so as there is little room for failed experiments: between CHI 2007 (May 2007) and now (June 2021), the monthly average carbon dioxide concentration has risen from 386.38 ppm to 418.73 ppm, as measured at the Mauna Loa Observatory in Hawaii [48]. The Intergovernmental Panel on Climate Change has estimated that stopping climate change at 1.5℃ will mean to limit atmospheric CO_2 to around 430 ppm [64], and we are on a path to exceed this perhaps as soon as 2041.

We urgently need sustainability research to have impact—a realisation that was already shared when members of the SHCI community came together at CHI 2014:

> "Thus far, sustainable HCI research has had little impact outside HCI. Most early system-development efforts within SHCI saw sustainability as an application domain for HCI business as usual. As we have come to realize the severity of the challenges of sustainability and the multiscalar, transdisciplinary nature of the processes that drive them, we have come to see sustainability less as an interesting research topic and more as a practical ethical imperative" [79].

It is clear that HCI researchers want to find solutions as many have enthusiastically dedicated their time and energy to sustainability research. But is our community equipped to do so? And if so, have we identified the appropriate path(s) to achieve sufficient impact?

3 CRITIQUES THROUGH THE YEARS

In what follows we explore many of the critiques through the years in order to understand what SHCI researchers are being asked to do, and how this might align with or exceed what we might regard as a traditional HCI skillset. Our first step was to establish a corpus of SHCI critiques. The aim thereby was to bring together a representative set of publications that at their core aim to reform the direction and approaches of the field, rather than to provide an exhaustive list of papers criticising aspects of SHCI. To locate these publications, we carried out online searches in Google Scholar and the ACM Digital Library using the keyword "sustainable HCI". We also drew on the reference lists of the 2017 book "Digital Technology and Sustainability" [40]. We defined a publication as an SHCI critique when one of its key contributions was to present a fundamental problem or gap in the SHCI literature and ask the community to respond in a certain way. If incorporated, we also included its reference list and the articles that cite it into our search. We used this approach to handle the diversity of possible publication venues and make our corpus as comprehensive as possible. Publications that purely focused on social and/or economic sustainability and not environmental sustainability, were excluded. This was both a practical and strategic decision. It allowed us to scope our corpus around the environmental concerns that predominated the field at its inception, so that we might later reflect on whether as a field we are closer now, 15 years later, to effecting environmental sustainability in and through computing.

A challenge we faced when establishing the corpus was in drawing the distinction between an SHCI critique to include and simply an SHCI-related publication. Many papers clearly either did or did not fit with our criteria, but for others the decision was more nuanced. Overtly critical papers that reviewed the past literature and offered a new call to action, were easily included. We also included papers situated or more critical of work in a particular domain drawing on particular analysis or specific literature, that also offered a call to shape research differently going forward. However, we excluded papers that reviewed SHCI literature to identify genres, trends or under-explored areas without actively criticising the existing research (e.g. [22, 31, 37]). Papers had to be in some sense 'pivotal' and reflective with a call to the community to adjust course. We made these decisions as carefully as possible, taking into account both the content and language of the paper, paying particular attention to statements about the paper's core contribution(s). Having been initially identified by the first author, these papers were discussed collectively with the wider author group. In each included critique we checked that we could pinpoint at least one section in the paper that critically addresses SHCI research and one call to action.

Our final corpus, which can be found in the supplementary materials, included 35 SHCI critiques. Without enforcing constraints on publication dates at the time of the research (Spring 2021), the critiques span the period from 2009 to 2018. Figure 1 illustrates the distribution, frequency and publication venues of each of these. As the visualisation highlights, the critique timeline can be divided into: a) a build-up phase from 2009 until 2013, where a handful of critiques were published each year; b) a significant peak in the number of critiques published, spanning 2014 and 2015 across multiple venues—15 (43%) of the critiques in our corpus stem from these two years; and c) a cooldown phase from 2016 onward with significantly fewer new critiques. Looking at the publication venues, we can see that the largest number of critiques by frequency (13) were published at CHI, followed by Interactions (7).

The key question driving our analysis is, *what are they asking HCI researchers to do?* The critiques each identify certain flaws in the then current SHCI approach, and while they are often less prescriptive about what needs to be done instead, they do hint at the importance of developing new competencies within the SHCI community. To identify these competencies, we applied a thematic analysis to the critique paragraphs and calls to action that had already been located in each paper; established themes were reviewed within the author group and iteratively refined to form the final competency categories. The following section shows the outcome of this analysis. Here, we provide a sketch of the essential new competencies entailed in these critiques in order to demonstrate the enormity of the challenge as currently conceived by the SHCI community itself. We hold for the moment the larger discussion around 'tipping points' [10] and adaptation to global change and 'collapse' [86], which assumes a more fundamental and unavoidable climate induced change to society—returning to these in the discussion.

3.1 The call for multidisciplinary expertise and collaboration

There is often a steep learning curve for those entering the SHCI field. Publications in this space regularly reference the work of orthogonal sciences, including climate science (e.g. greenhouse gas emissions [44, 68], carbon footprints [16, 67]), ecology (e.g. biodiversity [19, 62]), hydrology [43], air quality [1, 49] and the extremely complicated world of life-cycle analysis [12]. Not surprising, considering the relevance of these sciences. But learning about and keeping up with new developments in environmental fields needs to be done alongside readings on technological innovation and disciplines that have traditionally informed HCI work. The behavioural sciences have especially been emphasised, and how a deep understanding of users' values, emotions and inherent psychology is essential for SHCI (e.g. [13, 34, 52]). It has even been argued that "without addressing the underlying psychology that perpetuates our current state of unsustainability, there is little that computing can hope to achieve." [53].

To avoid staying in its own knowledge bubble, the SHCI community has been asked to collaborate more widely [79] and across disciplines [14], including collaborations with computer scientists and community organisations [78]. This is intended as an opportunity to learn from each other, to make SHCI research more impactful and to increase the community's understanding of the roots of current sustainability challenges. Bendor concludes that "we must seek allies and become allies to others. If sustainability is a 'bigger than self' issue [17], we too should grow both internally (by adding members) and externally (by assuming our place within Third Wave HCI)" [7].

HCI has always drawn from other disciplines—including psychology, sociology and information sciences—which allows for its unique understanding of humans, computers and the situatedness

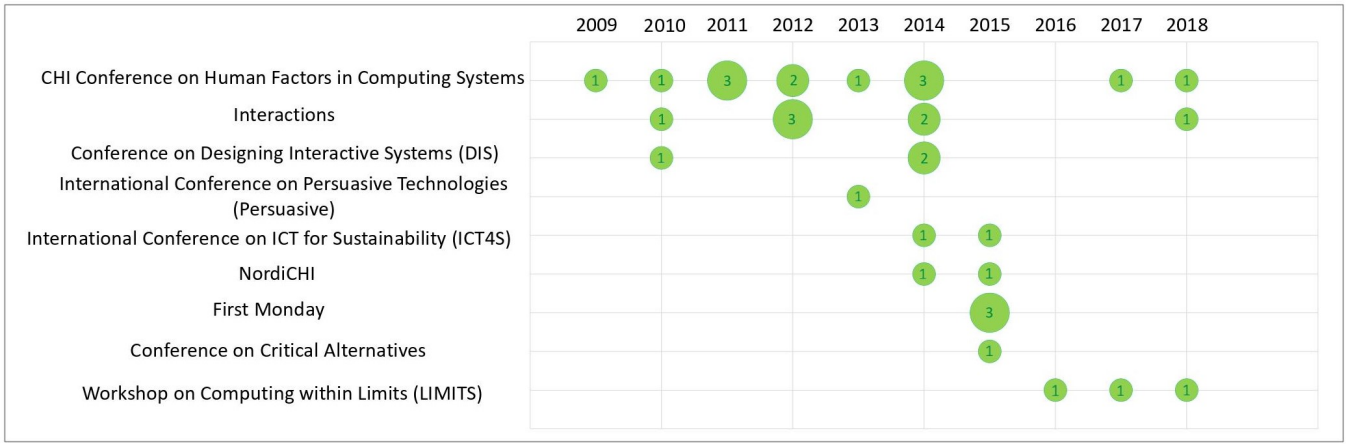

Figure 1: The distribution of SHCI critiques by year and publication venue. The size of the circles (radius) is proportional to the number of included papers (shown in each circle).

of their interactions. It would be nonsensical and counterproductive to question the benefits of multidisciplinary knowledge for our research endeavours. But asking the community to become experts in sustainability sciences as well, we must be careful not to spread ourselves too thin. If we have more and more knowledge and expertise to juggle, what does this mean with regard to our workload and ability to go into depth where necessary? At what point do we lose track of core disciplines or struggle to know what to teach at whatever institution we are employed at?

3.2 The call for a shared understanding of sustainability with agreed goals and metrics

In the midst of its multidisciplinary curriculum, the SHCI community has been urged to reach a shared understanding, definition or framing of sustainability. Observations that "definitions of sustainability in the sustainable HCI literature have become so broad as to become meaningless" [65] are potentially in tension with concern about adopting an overly narrow definition of sustainability [13], e.g. the calls that "future HCI research must take a more comprehensive view of the environmental, social, and economic facets that make up sustainability" [21] and to adopt a holistic view of sustainability and "go beyond being 'about' being green" [34]. Further contributions have encouraged the community to understand "sustainability as a supply (not demand) problem" [52] and "unsustainability not [as] a problem to be solved, but a complex and multifaceted condition with which we must grapple." [6].

Linked to the struggle to arrive at a sufficiently meaningful definition of sustainability is the repeated call to specify sustainability goals and metrics and to carry out evaluations (e.g. [14, 51, 80]). Portrayed as essential for progress in the field, such measurements of impact are argued to increase SHCI's relevancy and scientific basis [80], to "promote research to practitioners outside the field [and] help other researchers contribute to sustainability and gain acceptance for their work in the SHCI community" [72]. To combat "feel-good motivations" that are insufficient for the environmental crisis, projects could be evaluated against a checklist for impact [57]. Not an easy task as "the proxies generally used in evaluation (e.g. less energy or water consumption) may be poor indicators of such systems' effect on emissions because of effects outside the scope of analysis; in particular, direct and indirect rebound effects as described in the economic literature" [47]. Moreover, it has been noted that a focus on specifying goals and metrics in relation to authors' own particular definition of sustainability has fractured the community, miring it in unproductive debate about what sustainability *is* or *should be* [51]. Instead, Knowles et al. suggest orienting the field around climate change as a "big tent" for the myriad concerns of interest to SHCI.

Sustainability has always been a deeply contested concept [18], and so agreeing on a shared framing or definition is undoubtedly a challenging task. There are clear benefits should we succeed: establishing a coherent SHCI agenda and metrics for evaluation would provide valuable guidance for both established researchers and those entering the field. Can we get there without wasting time and effort in the philosophical wilderness? The critiques show the various conceptualisations of sustainability that are already promoted within the SHCI community. How should we decide which is the most appropriate? While HCI researchers regularly engage with philosophy, it is not for most our main area of expertise. So do we really want to undertake this work as an essential prerequisite of being able to do SHCI?

3.3 The call for systems thinking: simplified solutions won't solve structural problems

As the discussions within and outside of SHCI show, sustainability is an intricate concept. So, what does this intricacy mean for SHCI research? At the heart of many critiques sits what members of the community called for in 2014: "move beyond simple models to grapple with the full multi-scalar complexity of 'wicked' sustainability problems" [79]. Simple models do thereby link to computational thinking, which is rooted in the belief that with a toolbox of (algorithmic) methods, computer scientists are able to solve the worlds'

problems by applying the correct solution (type) to any particular problem (type). In lieu of such solutionism, a more systemic approach has been called for: "the failure to think systemically is a critical weakness in our understanding of the transformations needed to achieve sustainability"; as a means to overcome this "systems thinking provides the necessary bridge from computational thinking to sustainability practice" [25]. A shift from problems and solutions to situations and interventions, for example, "could beneficially be applied in numerous areas of HCI research and practice, and resonates with work in the 'third wave' of HCI research" [6]. On a methodological level, it has been argued that "the processes that give rise to the issues indexed by the term sustainability are larger in time, space, organizational scale, ontological diversity, and complexity than the scales and scopes addressed by traditional HCI design, evaluation, and fieldwork" [79]. Consequently those doing SHCI should "do research that considers longer time scales" (ibid).

Many critiques address the need for SHCI research to be contextually embedded. It should acknowledge that consumption is shaped by infrastructures, technologies and institutions [85] and that sustainability is balanced with other concerns and practices [34]. The inter-personal dynamics in social settings like households add another layer of complexity. Here, "HCI designers can learn from the vast amount of social, cultural and anthropological research discussing how practices change in everyday life". And because the focus of consumption practices is often non-environmental, "it might not be useful to focus on consumption or the environment at all" [85]. In general, the community has been asked to think outside the box, and reimagine and create new approaches to tackle challenges of resource and carbon reduction [38]. Macrostructures [61] and retrofitting [88] for example are said to deserve attention. Other suggestions include "having 'enough' as a central design theme for applications that support communication and information access" [34], to reconfigure what is old and new [35] and to "focus on a generative, positive theme of more to counter limits: more community, more shared activity, more collaboration, more shared moral sense of sustainability, more neighborliness, more empowerment" [33]. Or not to design at all. To better understand when technology is and is not appropriate as a solution, it could be useful to present prototypes and abandoned alternatives alongside final designs, and the reasons for why those options were not pursued [6]. As researchers come to HCI through a highly diverse mix of disciplinary backgrounds, parts of the community might not currently find themselves adequately trained and equipped to excel at systems thinking. For those with an HCI education, we know there are gaps in the curriculum which leave graduates ill-prepared to take on the ethical challenges they face: a lack of e.g. (perceived or real) knowledge, resources and relevance regularly prevents the integration of sustainability principles and practices into the computing curriculum [59]. And even when these factors are eliminated, it is not necessarily clear how to best achieve a smooth and profound integration across modules that "touches" students [27]. The above critiques call for a radical overhaul of HCI curriculum to enable SHCI researchers to be able to think in ways needed to tackle sustainability. Furthermore, as fair as it may be to say that 'solutionism' is problematic, where does that leave HCI researchers? Designing technology solutions is, after all, what HCI as a discipline has largely evolved to do. What good is theorising even at the systems level if it does not ultimately lead to new insights regarding opportunities for technological intervention? We also know that there are pragmatic challenges here which have never fully been resolved. If we look at desired publications timescales, how realistic is it to conduct research over long timescales that requires a deep understanding of extra-university institutions and infrastructures?

3.4 The call to support system change and activism

Arisen from a more holistic thinking, a frequent call is to design for system change instead of individual behaviour change. This includes efforts to support activism and mass movements (e.g. [30, 51]) as well as to influence institutions, infrastructures and policies [79]. The main idea is that interactive technologies can be used to address broader levels of community engagement [46] and societal transformation [30] rather than to target each user only within the context of their personal life: "if research disciplines (ICT4S, HCI, Ubicomp) are to successfully progress towards a more sustainable future they must begin to consider limits to growth and more regularly attempt at more radical, more impactful changes (e.g. designing for non-reliance, a zero carbon future for non-negotiable), instead of putting the majority of its efforts into low(er) impact persuasion (e.g. attending to the impacts of background tasks)" [39].

This does not mean that persuasion should be abandoned. Rather, the aim is to apply the accumulated knowledge around persuasive technology more fruitfully: "By focusing not on connecting people to their actions and their consequences, but on connecting people through their actions and their consequences, we can approach persuasive technologies as ones whose intent is to persuade people of the effectiveness of collective action and of their own positions within those collectives" [23]. Supporting people to engage in activist behaviours [30] is thereby seen as a particularly promising strategy as these behaviours, together with major lifestyles changes, "are ultimately the behaviours that have the potential for significant impacts for sustainability." [52]. This is mirrored in the suggestion that high-impact areas (indoor climate, travel, food, and purchases) "might be most effectively addressed in conjunction with policy initiatives and broader public support" because they "are so technologically, socially, and culturally mediated." Such calls raise important questions, like those about the attribution of responsibility [23] and protection of democracy: "Can we identify ways to activate individuals and communities without jeopardizing that which makes democracy worth protecting, that is, without bringing to life some grotesque version of a (more or or less) benevolent eco-dictatorship?" [7].

The critiques highlight the potential impact gain by redirecting efforts towards system change. In part recognising the endemic pace of innovation and uptake of research, they argue that SHCI should support or amplify the voices of activists, communities and larger groups to bring about and accelerate this change, c.f. [2]. Yet this raises new questions for SHCI researchers as to our position, role and moral responsibility in this, if we want to successfully and fairly support system-level change. How can we encourage individuals and communities to engage in activism? How can we ensure that the systems allow them to democratically promote

their personal sustainability priorities, and not ours? How can we establish collaborations with existing policy initiatives? And in between individual, corporate and state responsibility, what is ours? Are we now activists as well as researchers? In what proportion? What happens when the institutions that support our research do not support our activism? Building knowledge, relationships and trust takes time, for how long can we maintain these engagements? And what happens to these groups that come to depend on us afterwards?

3.5 The call to re-imagine the economy and consider limits to growth

The questions of responsibility and system change also emerge in the community's discussions on economic sustainability, another pillar of the the popular three-pillar conception of sustainability (besides environmental and social) [69]. Economic concerns have arguably not received enough attention in SHCI [21] (and HCI more generally, e.g. [26]), which hampers the community's ability to address sustainability holistically.

Where 'the market' and 'nature' have been "construed as natural facts rather than as social ones", questioning such framings can open up new areas for engagement and research [23]. (The design of) information technologies, which act as a lens through which we perceive contexts and systems can, thus, play a critical role in driving change (ibid). This belief is echoed in the discussion on (ecological and social limits to economic) growth: "Coming out of our roles as technology specialists aiming to produce knowledge and novel technologies in the service of increasing economic growth or shareholder value is an opportunity to reassess the centrality of technology in our work. Technology is extremely powerful, and our facility with it gives us relatively unique powers." [78]. To make a positive difference, the community has been encourage to focus "on a) ecological limits, b) creating designs and artifacts that do not further a cornucopian paradigm, and c) fundamental human needs" and to design disintermediated human-computer systems, which "can have the dual benefit of improving societal sustainability while decreasing inequality and the political economy problems that are prevalent today" [71]. To begin to address the fundamental tension "between sustainability and the aim of economic growth that supports and orients, if implicitly, the industry of which HCI is part" [79], some have called for a new model for the digital economy, with "technologies relying less on instrumental purposes of efficiency connected with corporate profit... (motivated by research paradigms grounded in the belief of infinite economic growth) and relying more on volitional and value-laden aspects underlying people's use of technologies" [51] (quoting Naomi Klein [50]).

The finiteness of natural resources and tension between sustainability and economic growth has led to SHCI community to ask fundamental questions about current economic systems and limits to growth. Questions that have profound implications for sustainability work. But re-imagining and designing for new economic models and potentially degrowth within a system that is built upon economic growth is difficult. It requires much imagination, intricate knowledge of political and economic systems, and the confidence—as non-economists by training—to apply this knowledge towards ideas that are far from uncontroversial. Even with all of those in place, what is the impact SHCI can have here? Are we able to affect an economic system that is being fueled by so many outside forces?

4 CRITIQUE ADOPTION

In 2017, Raghavan and Pargman observed that "while some of this [Sustainable HCI and Sustainable Computing] work has offered well-grounded critique, it has often fallen short on practical advice and on suitable techniques that are concrete enough to be actionable" [71]. This observation raises important questions about the practicability and tangibility of published SHCI critiques. To what extent has the community been able to translate their advice into action? What are the difficulties they have faced in the process? Can we really do *all* of what is entailed in the above critiques? Have we, perhaps, taken on too much?

To explore the integration of the critiques within the community and to understand whether any clear trends were observable, we developed a corpus of relevant SHCI publications for analysis from CHI proceedings between 2019 and 2021. Limiting ourselves to CHI, we were hoping to track changes within a specific research community. This does mean, however, that our analysis pertains only to the CHI community, reflecting the work of researchers who publish at CHI and reviewers and program committee members serving CHI who collectively determine which SHCI works get published. We chose 2019 as our starting point, as this allowed approximately a decade since the birth of the sub-field—arguably enough time for a period of reflection, impact and change—to avoid overlap with the critique corpus, and three years of proceedings to provide a sufficient sized sample of current literature without over-representation of any one conference proceeding. An initial set of publications was generated by searching the ACM Guide to Computing Literature via the ACM Digital Library using the keywords 'sustainability' and 'sustainable'. Focusing on research articles, we obtained 568 results. We then manually checked the search results for relevance. In line with the criteria in [22], we decided that for a paper to be regarded as an SHCI paper, one of its main contributions had to be sustainability-related. Papers that did not explicitly present sustainability as a key motivator for their research were excluded. To match the critique corpus, papers had to target sustainability in an environmental/ecological sense—either exclusively or besides other kinds of sustainability (e.g. economic, social) to be included in the corpus. After manually checking the search results against these criteria, we were left with 27 papers, which constituted our corpus: 7 from 2019, 8 from 2020 and 12 from 2021. The corpus can be found in the supplementary materials.

4.1 Community and policy awareness instead of individual behaviour change

A key shift within the SHCI literature at CHI is the one away from (extensively criticised) individual behaviour change approaches towards research that at its core aims to bring about a deeper understanding of sustainability issues and interventions among communities and decision-makers. The underlying scientific insights are obtained through a variety of methods, often those that involve the presence of community members, like ethnographic (e.g. [4, 54, 56, 73]) and co-design activities (e.g. [19, 41, 42, 60]). While interventions can make a difference and set an example (see

e.g. [19, 77]), the focus tends to be on the knowledge created during the research or design process and during subsequent reflections. This is mirrored in a lack of traditional quantitative impact evaluations in favour of qualitative descriptions. As well as in a large number of non-interventional studies (e.g. [8, 36, 45, 82, 89, 90]): with the goal to create knowledge, many studies explore existing environments and systems without feeling the need to alter them. Instead, a key contribution of these studies can be to explicitly open up design/research spaces for impactful follow-up work (within and outside of academia), see e.g. [4, 56, 73, 89].

The shift shows that the SHCI community has responded to several calls from critics, namely to stop focusing on individual behaviour change research, to design with and for communities and to think contextually. The nature of the resulting research, however, can make it difficult to measure its impact. This leads to a question the SHCI community has grappled with previously: how can we verify that our efforts will bear fruit eventually? If the current work focuses on generating contextual understanding and opening up design spaces, are we simply passing the question of impact onto the next SHCI generation?

4.2 Speculation instead of prescription

With the goal shifting from behaviour change to awareness expansion, we also note a shift in the underlying approach from prescription to reflection and speculation. When DiSalvo et al. [22] analysed the SHCI landscape in 2010, they classified 45% of it as persuasive technology, for which "the standard approach is to design systems that attempt to convince users to behave in a more sustainable way". This is not echoed in our corpus, which contains only one study that uses an openly persuasive approach [77]; a few other studies have an indirect persuasive element as they encourage reflection [15], support learning [19, 20] or raise awareness [76]. What we see instead is a substantial amount of speculative design (e.g. [8, 15, 42, 81, 92]). Often participatory, such design research is more experimental and possibility-oriented in nature and aims to expand the research community's horizon and encourage reflection. It thereby forgoes a more stringent behaviour classification—one that underpins traditional persuasive work. The design principles in Biggs & Desjardins [8] succinctly capture this orientation: "First, we aimed to resist design directions that sought to 'solve' climate change or change the behavior of research participants. Second, we wanted to validate and integrate the practices of Seattle's everyday cyclists. [...] Finally, we wanted to design for noticing and awareness as a way to allow nuanced, open ended narratives about intersections of cycling and sea level rise to form from participant's histories of situated practice as Seattle cyclists. The High Water Pants embody these tenets."

Back in 2012, Brynjarsdóttir et al. [13] highlighted how "persuasion narrows our vision of sustainability"; our CHI corpus does indicate a turning point. The shift towards speculative design research enables researchers to not impose their understanding of sustainability and sustainable behaviour onto others, including their participants. Avoiding such prescriptions allows us to get on with our work instead of philosophising over metrics and definitions. And it can make the resulting outputs more inclusive and practice-oriented. Yet, there remains the wish to have impact and the question if speculations will suffice. If not, what kind of subsequent HCI or non-HCI work is needed to bridge that gap?

4.3 Holistic perspectives instead of simple metrics

The papers in our corpus frequently view environmental and other kinds of sustainability, notably social and economic sustainability, as interlinked. Thus, they tend to be addressed together, rather than researched separately, to allow for a deeper understanding of all aspects and their interplay (e.g. [20, 41, 42, 54, 73, 91]). Detailed reflections on the characteristics and meaning of specific contexts, objects and practices illustrate the community's holistic and systemic ways of thinking. The methodological choices indicate this too: for research with a substantial human element, authors tend to integrate one or several qualitative methods in their study design, including the aforementioned ethnography, interviews (e.g. [81, 82, 90]) and workshops (e.g. [41, 60, 89]). This does not mean that quantitative methods are absent from SHCI research, but rather that they are used to evaluate technical systems, not human ones. Calculations of energy demand and/or greenhouse gas emissions [45, 68, 89] fall into this category.

The holistic research perspectives we see in recent SHCI work answer to critics' calls to move away from overly narrow definitions of sustainability and to embrace systems thinking. As environmental concerns remain on the agenda, they are studied in context, not isolation. This aligns with third-wave thinking and prevents oversimplifications, for example in decision-making processes. Acting on the findings while honouring the captured complexity, however, comes with new challenges. How do we introduce computational interventions into complex contexts without falling prey to computational thinking? Or if computational interventions are not the solution, how can we realise impact from the knowledge created through our research?

4.4 Diverse explorations beyond resource consumption

While DiSalvo et al. [22] did not specify the frequency with which the papers in their corpus targeted specific aspects of sustainability (e.g. energy consumption, waste reduction), Brynjarsdóttir et al. [13] did so in 2012 for the persuasive technology literature they analysed: they found that half the papers addressed energy consumption, a quarter focused on other types of resource consumption and the remaining quarter targeted sustainable transportation, air quality, CO_2 emissions or went beyond a single topic. (As persuasive technology only describes one type of SHCI research, we need to be careful when making comparisons.) What we see in our corpus is that energy has remained a key theme (e.g. [60, 76, 81, 89, 90]), although the research approaches and contexts have changed, as described above. A subcluster of energy-related research explores the carbon footprint and, more generally, the (un)sustainability of digital technology. This includes online services [68, 89], web development [91], machine learning [76] and digital materials [60], and can be conceptualised as work on sustainability *in* design rather than sustainability *through* design [58]. Beyond energy, topics of interests include biodiversity [8, 19, 20, 41], food [15, 41, 42, 77]

and agriculture [4, 41, 54, 55], fabrication [56, 83, 92], sea-level rise [8, 82], and (e-)waste [73, 92].

The list of research topics reveals that the SHCI community has embraced sustainability research beyond energy and resource consumption. This shows the versatility of SHCI work and answers to calls for innovation, outside-the-box thinking and agenda expansion in SHCI (e.g. [21, 63, 70]). But while topics like fabrication, food and biodiversity certainly deserve attention, a question we might need to ask ourselves is whether we are moving away from an original desire to mitigate climate change? While we may make other worthy contributions related to sustainability—environmental and otherwise—does this signal that we are lost as to how SHCI might meaningfully contribute to the global effort to preserve the habitability of this planet?

5 DISCUSSION

Less than fifteen years old, the SHCI community now has a history of self-critical evaluation of its direction. Particularly with a problem as hard to gain traction upon as sustainability, this seems entirely healthy. In this paper we analyse this SHCI critique landscape to better understand what they ask of the community, and also their influence. Our analysis shows a substantial expansion of knowledge and skills required of SHCI researchers. In addition to expertise in what we might regard as 'traditional' core areas of HCI, like interface design, user psychology and technological innovation, SHCI researchers are asked to be well-versed in various aspects of sustainability sciences, philosophy and economy. An they are urged to engage in systems thinking, activism and cross-disciplinary collaborations. We do not want to question the relevance of such knowledge or engagement. Rather, we are concerned that it is a potentially intractable ask of HCI. Not only does it have profound implications for researchers in and entering the field, their epistemology and engagement with communities. But it also suggests a curriculum overhaul to equip students with the skills and ways of thinking they require.

Have the critiques made a difference? Our critique adoption analysis indicates that they have indeed shaped the nature of subsequent research. Positively, this would mean that the community brings adaptability and communication skills to the table, besides its deeply rooted, shared passion for "doing good" [5]. More specifically, the community has understood the limitations of persuasive, individual-focused projects and moved towards more diverse, qualitative and speculative SHCI research. Viewed through a historical lens, SHCI has shifted from second-wave approaches towards those anchored in the third wave, and has found creative ways to capture the complexity of (un)sustainability and broaden the SHCI agenda to topics including biodiversity, food and fabrication. We have seen inspiring and thought-provoking studies that balance a variety of concerns while helping us to see things in a new light.

We fully recognise that sustainability is more than just climate change. We do not wish to discard projects that are engaging with communities and stakeholders effectively, and having various positive impacts to learning, theory and practice. Or those that are helping us explore, provoke, or enhance our understanding of sustainability profoundly in other ways. However, given the urgency, importance and existential threat of climate change—and urgent need for direct, evaluable paths to help mitigate this—our analysis does not, sadly, indicate that we have found them.

It's important for SHCI to again reflect, has the research we have carried out during the past fifteen years made enough of a difference to climate change? Are we on a trajectory to do so soon enough? And if not, could we be? Similar questions about impact have undoubtedly played a role in many of the critiques we have presented in this paper; they are at the heart of what motivates many SHCI researchers. As Mankoff put it: "I've seen the same concern crop up in various forms in reviews and on thesis committees I've been privy to: how much of an impact do sustainability projects really have, and does it justify the cost, time, and effort put into them?" [57]. Where speculative and qualitative research has allowed us to embrace sustainability's complexity, has it not also decreased our ability to measure impact? Have we painted ourselves into a corner with no direct path to driving change?

Our review of the SHCI critiques is telling a story: technologists cannot be expected to do the work of policy makers. Even if our community would find ways to acquire all the skills that are called for and be fully equipped to take on the underlying structural challenges to society, it is not us, but the policy makers that need to implement these changes. This does not mean that we cannot or should not contribute, but it means that we should challenge the narrative that we can rely on technology to save us, just as we challenged the narrative that climate change is an individual behaviour change problem. SHCI work to date has assumed that policy makers will fail to implement some form of constraint [87] (e.g. an extraction cap, emissions taxes, or limits on consumption); and under those conditions, it seems that the ways in which we can effectively apply traditional HCI skills towards climate change mitigation—without acquiring expertise in other disciplines—are limited. But what if we change this assumption? If bold and ambitious climate policy were in place, could SHCI constructively apply a more familiar and well-honed skillset to help realise those policies in a whole host of domains? We think so. Let's call this pathway 'Green Policy informatics'.

In Green Policy informatics, HCI has a clearer role in working towards and staying within the emission constraints set by policy makers. This could provide new focus for SHCI. We could help ensure digital systems bring needed transparent accounting and accountability, support complex decision making under uncertainty, and enable the deconstruction of popular myths about the energy and carbon impacts of everyday life. Historically, efficiencies delivered by computing have led to wide-ranging rebound effects, where efficiency gains through automation counter-intuitively result in an *increase* in carbon emissions. Yet, in a world where there are limits set to energy and resources, an efficiency gain becomes an important means of staying within this budget [28]. Previously discounted avenues of design may even have new value under Green Policy informatics: 'Smart' solutions (e.g. for homes, cities) and persuasive technologies could make a valuable contribution—as long as due consideration is given to the cost-benefit ratio to ensure they deliver more emissions reductions than they cost. Data visualisation can usefully be applied to track compliance with emissions targets at various scales, for example adding clarity to the complex dynamics of multiple emission sources. Interface design and usability will be in high demand given the many levels and actors throughout

society at which sustainability must be considered, as digital systems are introduced to streamline and transition operations across the global economy. An important (and comfortable) role for SHCI can now even include making sure that the systems developed to support a radical transition are user-centred (e.g. by experts using building management and urban planning systems). SHCI already has more recent third-wave skills for requirements gathering, participatory design, and understanding the implications of climate measures in different contexts and for different populations.

That starting from an alternative assumption can open up a different space for SHCI has been shown before: Collapse informatics [87] did just this by preparing for the case in which humanity is unsuccessful in preventing climate change in advance of societal collapse caused by its effects—and it seems wise to prepare for every eventuality! Similarly, what we are proposing as fruitful territory for SHCI is closely aligned with suggestions made by Blevis et al. back in 2010 [10]: when they encouraged SHCI researchers to contribute towards "the design of digital networking and interactive technologies that can help people at various levels—as individuals, small groups, governments, and global bodies—plan and prepare for the orderly adaptation to these effects." These are reasonable and realistic contributions to ask of SHCI if what we are responsible for is not also the work of policy makers, but facilitating an effective digital transition. With this in mind, we can circle back to where we started, this time better understanding the contributions we can make not only in preparation for but also to mitigate collapse.

We do not intend to imply that bringing about or enacting such policy is without its challenges, or indeed, that we should simply trust or leave something so critical to politicians. Rather, as Dourish reflects: "interactive systems are also lenses through which we encounter the world" [23], framed by broader social, political and economic processes. As such, as Green Policy informaticians, we have a potentially critical role in addressing the urgent problems of environmental sustainability.

Our alternative assumption does not mean that the current SHCI work loses its value: sustainability has multiple dimensions, and system change is endemic to meeting this existential crisis. We need all of HCI's holistic design skills to get the message of Green Policy informatics across to policy makers. We need to drive policy makers to meet their responsibility when it comes to climate change mitigation and implementation of socially, economically and environmentally just and sustainable systems. Let's not allow them to frame the climate change debate as an individual behaviour change or a technologists' problem. We can bring our knowledge and expertise to the table, but to focus on what we do best, we need them to enact more radical policies.

6 LIMITATIONS

Reflections on a field as diverse and innovative as HCI and on the passionately discussed topic of sustainability require both methodological and value choices—choices for which other researchers may reach different conclusions. Establishing our corpora entailed a multitude of decisions which include but are not limited to the search terms, publication periods and venues, and the definition of a critique. During the decision-making process, we tried to carefully weigh the implications of possible options, discussing them within the author group and documenting them as we went along. However, as we are seeing the research through the lenses of our own backgrounds, expertise and priorities, other researchers may have made different decisions.

The same applies to the analysis and discussion. In particular, there is the question of how to weigh the importance of climate change mitigation as opposed to other sustainability topics. As we have seen in our SHCI critique corpus, there has been much discussion about the framing of sustainability and foci within the field, with researchers arguing for both narrow and broad sustainability framings. In the discussion of our work, we have put particular emphasis on climate change mitigation due to its key role in motivating the creation of SHCI and the imminent existential threat it poses. We have done this in the understanding that differently framed work can make other important contributions.

In addition, we have opted to define a 'traditional HCI skillset' as informed by the three HCI paradigms. We have done this to capture the historical developments in HCI and how they have informed what HCI researchers as a group are most skilled at doing. This does not mean that we are unaware of the growing diversity within the SHCI community; its members' different backgrounds and skillsets being one of its core strengths. Rather, our definition is based on the understanding that we should not expect each individual researcher to cover the entire array of additional skills the critiques call for, and that HCI as a discipline has evolved around the design and analysis of interactive technologies.

7 CONCLUSION

Sustainability is a multifaceted concept, and there are many aspects of our everyday lives and systems that can be improved to help protect the environment and its ecosystems. During its young history the SHCI community has explored a variety of these aspects, with a recent embrace of topics like biodiversity, food and fabrication. We need this work, but it is existentially undermined by out of control climate change. Harbingers in form of temperature records and natural disasters are giving us a first taste of what we can expect if that endeavour fails, one that drove the creation of SHCI in the first place, and which remains acutely important.

Part of the untold story of SHCI is the emotional toll this work can take on those who do this research. Many entered this area with enthusiasm and a strong sense of purpose, only to find it increasingly difficult to locate meaningful technological solutions to the problems that motivated us. Our hope is that this paper offers a new pathway and narrative: to realise that we can't do it all, but we can do something. Analysing the SHCI critiques and their adoption, we have come to understand SHCI as a community with a diverse skillset and the ability to listen to one another and to embrace complexity. After fifteen years of exploring the possibilities for impact, we can see how difficult it is for SHCI to affect climate change independent of major changes in climate policy. Beyond the current diverse (design) explorations and speculation, we can use our traditional design and research skills to help facilitate a smoother and more effective transition to a carbon-constrained future, but it is policy makers who must set this transition in motion. In this context, we propose a reasonably scoped contribution from SHCI in the form of 'Green Policy informatics'.

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REFERENCES

[1] Paul M Aoki, RJ Honicky, Alan Mainwaring, Chris Myers, Eric Paulos, Sushmita Subramanian, and Allison Woodruff. 2009. A vehicle for research: using street sweepers to explore the landscape of environmental community action. In *Proceedings of the 2009 CHI Conference on Human Factors in Computing Systems*. 375–384.

[2] Paul M. Aoki, R. J. Honicky, Alan Mainwaring, Chris Myers, Eric Paulos, Sushmita Subramanian, and Allison Woodruff. 2009. A Vehicle for Research: Using Street Sweepers to Explore the Landscape of Environmental Community Action. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Boston, MA, USA) *(CHI '09)*. Association for Computing Machinery, New York, NY, USA, 375–384.

[3] Liam J Bannon. 1991. From human factors to human actors: The role of psychology and human-computer interaction studies in system design. In *Design at work: Cooperative Design of Computer Systems*, J. Greenbaum and M. Kyng (Eds.). Elsevier, 25–44.

[4] Jeffrey Bardzell, Shaowen Bardzell, and Ann Light. 2021. Wanting To Live Here: Design After Anthropocentric Functionalism. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–24.

[5] Oliver Bates, Vanessa Thomas, and Christian Remy. 2017. Doing good in hci: Can we broaden our agenda? *Interactions* 24, 5 (2017), 80–82.

[6] Eric PS Baumer and M Six Silberman. 2011. When the implication is not to design (technology). In *Proceedings of the 2011 CHI Conference on Human Factors in Computing Systems*. 2271–2274.

[7] Roy Bendor. 2018. Sustainability, hope, and designerly action in the anthropocene. *Interactions* 25, 3 (2018), 82–84.

[8] Heidi R Biggs and Audrey Desjardins. 2020. High Water Pants: Designing Embodied Environmental Speculation. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. 1–13.

[9] Eli Blevis. 2007. Sustainable interaction design: invention & disposal, renewal & reuse. In *Proceedings of the 2007 CHI conference on Human Factors in Computing Systems*. 503–512.

[10] Eli Blevis and Shunying Blevis. 2010. Hope for the best and prepare for the worst: Interaction design and the tipping point. *Interactions* 17, 5 (2010), 26–30.

[11] Susanne Bødker. 2006. When second wave HCI meets third wave challenges. In *Proceedings of the 4th Nordic Conference on Human-Computer Interaction: Changing Roles*. 1–8.

[12] Leonardo Bonanni, Matthew Hockenberry, David Zwarg, Chris Csikszentmihalyi, and Hiroshi Ishii. 2010. Small business applications of sourcemap: a web tool for sustainable design and supply chain transparency. In *Proceedings of the 2010 CHI Conference on Human Factors in Computing Systems*. 937–946.

[13] Hronn Brynjarsdóttir, Maria Håkansson, James Pierce, Eric Baumer, Carl DiSalvo, and Phoebe Sengers. 2012. Sustainably unpersuaded: how persuasion narrows our vision of sustainability. In *Proceedings of the 2012 CHI Conference on Human Factors in Computing Systems*. 947–956.

[14] Jay Chen. 2016. A strategy for limits-aware computing. In *Proceedings of the Second Workshop on Computing Within Limits*. 1–6.

[15] Janghee Cho, Laura Devendorf, and Stephen Voida. 2021. From The Art of Reflection to The Art of Noticing: A Shifting View of Self-Tracking Technologies' Role in Supporting Sustainable Food Practices. In *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–7.

[16] Adrian K Clear, Mike Hazas, Janine Morley, Adrian Friday, and Oliver Bates. 2013. Domestic food and sustainable design: a study of university student cooking and its impacts. In *Proceedings of the 2013 CHI Conference on Human Factors in Computing Systems*. 2447–2456.

[17] Tom Crompton. 2010. *Common Cause: The Case for Working with Our Cultural Values*. https://assets.wwf.org.uk/downloads/common_cause_report.pdf (accessed: 17 August 2021).

[18] Aidan Davison. 2001. *Technology and the contested meanings of sustainability*. Suny Press.

[19] Tshering Dema, Margot Brereton, Michael Esteban, Alessandro Soro, Sherub Sherub, and Paul Roe. 2020. Designing in the network of relations for species conservation: The playful Tingtibi community birdhouse. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. 1–14.

[20] Tshering Dema, Margot Brereton, and Paul Roe. 2019. Designing participatory sensing with remote communities to conserve endangered species. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. 1–16.

[21] Tawanna Dillahunt. 2014. Toward a deeper understanding of sustainability within HCI. In *Workshop on Sustainability. What have we learned*.

[22] Carl DiSalvo, Phoebe Sengers, and Hrönn Brynjarsdóttir. 2010. Mapping the landscape of sustainable HCI. In *Proceedings of the 2010 CHI Conference on Human Factors in Computing Systems*. 1975–1984.

[23] Paul Dourish. 2010. HCI and environmental sustainability: the politics of design and the design of politics. In *Proceedings of the 8th ACM conference on designing interactive systems*. 1–10.

[24] Emanuel Felipe Duarte and M Cecília C Baranauskas. 2016. Revisiting the Three HCI Waves: A Preliminary Discussion on Philosophy of Science and Research Paradigms. In *Proceedings of the 15th Brazilian Symposium on Human Factors in Computing Systems*. ACM, 38.

[25] Steve Easterbrook. 2014. From computational thinking to systems thinking. In *The 2nd international conference ICT for Sustainability (ICT4S), Stockholm*.

[26] Hamid Ekbia and Bonnie Nardi. 2015. The political economy of computing: The elephant in the HCI room. *Interactions* 22, 6 (2015), 46–49.

[27] Elina Eriksson and Daniel Pargman. 2014. ICT4S Reaching Out: Making sustainability relevant in higher education.. In *ICT4S*.

[28] Charlotte Freitag, Mike Berners-Lee, Kelly Widdicks, Bran Knowles, Gordon Blair, and Adrian Friday. 2021. The climate impact of ICT: A review of estimates, trends and regulations. *arXiv preprint arXiv:2102.02622* (2021).

[29] Jon Froehlich, Leah Findlater, and James Landay. 2010. The design of eco-feedback technology. In *Proceedings of the 2010 CHI Conference on Human Factors in Computing Systems*. 1999–2008.

[30] Eva Ganglbauer, Wolfgang Reitberger, and Geraldine Fitzpatrick. 2013. An activist lens for sustainability: From changing individuals to changing the environment. In *International Conference on Persuasive Technology*. Springer, 63–68.

[31] Elizabeth Goodman. 2009. Three environmental discourses in human-computer interaction. In *CHI'09 Extended Abstracts on Human Factors in Computing Systems*. 2535–2544.

[32] Jonathan Grudin. 2017. From tool to partner: The evolution of human-computer interaction. *Synthesis Lectures on Human-Centered Interaction* 10, 1 (2017), i–183.

[33] Xinning Gui and Bonnie Nardi. 2015. Foster the" mores", counter the" limits". *First Monday* (2015).

[34] Maria Håkansson and Phoebe Sengers. 2013. Beyond being green: simple living families and ICT. In *Proceedings of the 2013 CHI Conference on Human Factors in Computing Systems*. 2725–2734.

[35] Maria Håkansson and Phoebe Sengers. 2014. No easy compromise: Sustainability and the dilemmas and dynamics of change. In *Proceedings of the 2014 conference on Designing interactive systems*. 1025–1034.

[36] Andrea Hamm, Yuya Shibuya, Stefan Ullrich, and Teresa Cerratto Cerratto Pargman. 2021. What Makes Civic Tech Initiatives To Last Over Time? Dissecting Two Global Cases. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–17.

[37] Lon Åke Erni Johannes Hansson, Teresa Cerratto Pargman, and Daniel Sapiens Pargman. 2021. A Decade of Sustainable HCI: Connecting SHCI to the Sustainable Development Goals. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–19.

[38] Mike Hazas, AJ Bernheim Brush, and James Scott. 2012. Sustainability does not begin with the individual. *Interactions* 19, 5 (2012), 14–17.

[39] Mike Hazas, Adrian Clear, Adrian Friday, Bran Knowles, Carolynne Lord, and Oliver Bates. 2015. Exploring (un) sustainable growth of digital technologies in the home. (2015).

[40] Mike Hazas and Lisa P Nathan (Eds.). 2017. *Digital Technology and Sustainability: Engaging the Paradox (1st ed.)*. Routledge.

[41] Sara Heitlinger, Nick Bryan-Kinns, and Rob Comber. 2019. The right to the sustainable smart city. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. 1–13.

[42] Sara Heitlinger, Lara Houston, Alex Taylor, and Ruth Catlow. 2021. Algorithmic Food Justice: Co-Designing More-than-Human Blockchain Futures for the Food Commons. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–17.

[43] Tad Hirsch and Ken Anderson. 2010. Cross currents: water scarcity and sustainable CHI. In *Extended Abstracts of the 2010 CHI Conference on Human Factors in Computing Systems*. 2843–2852.

[44] Rachel Jacobs, Steve Benford, Mark Selby, Michael Golembewski, Dominic Price, and Gabriella Giannachi. 2013. A conversation between trees: what data feels like in the forest. In *Proceedings of the 2013 CHI Conference on Human Factors in Computing Systems*. 129–138.

[45] Jason T Jacques. 2020. CHI 2020: Right Here, Right Now? A bottom-up approach to estimating the carbon emissions from more than twenty years of CHI conference travel. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems*. 1–13.

[46] Somya Joshi and Teresa Cerratto Pargman. 2015. In search of fairness: critical design alternatives for sustainability. In *Proceedings of the fifth decennial Aarhus conference on critical alternatives*. 37–40.

[47] Samuel J Kaufman and M Six Silberman. 2011. Rebound effects in sustainable HCI. In *Sustainable Interaction Design in Professional Domains, workshop at CHI 2011*. Citeseer.

[48] R. F. Keeling, S. J. Walker, S. C. Piper, and A. F. Bollenbacher. 2021. *Scripps CO_2 Program, Atmospheric CO_2 Data.* https://scrippsco2.ucsd.edu/data/atmospheric_co2/primary_mlo_co2_record.html (accessed: 15 August 2021).

[49] Sunyoung Kim and Eric Paulos. 2010. InAir: sharing indoor air quality measurements and visualizations. In *Proceedings of the 2010 CHI Conference on Human Factors in Computing Systems*. 1861–1870.

[50] Naomi Klein. 2015. *This changes everything: Capitalism vs. the climate*. Simon and Schuster.

[51] Bran Knowles, Oliver Bates, and Maria Håkansson. 2018. This changes sustainable hci. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–12.

[52] Bran Knowles, Lynne Blair, Paul Coulton, and Mark Lochrie. 2014. Rethinking plan A for sustainable HCI. In *Proceedings of the 2014 CHI Conference on Human Factors in Computing Systems*. 3593–3596.

[53] Bran Knowles and Elina Eriksson. 2015. Deviant and guilt-ridden: Computing within psychological limits. *First Monday* (2015).

[54] Marvin Landwehr, Philip Engelbutzeder, and Volker Wulf. 2021. Community Supported Agriculture: The Concept of Solidarity in Mitigating Between Harvests and Needs. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–13.

[55] Szu-Yu Liu, Shaowen Bardzell, and Jeffrey Bardzell. 2018. Out of control: reframing sustainable HCI using permaculture. In *Proceedings of the 2018 Workshop on Computing within Limits*. 1–8.

[56] Szu-Yu Liu, Shaowen Bardzell, and Jeffrey Bardzell. 2019. Symbiotic encounters: HCI and sustainable agriculture. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. 1–13.

[57] Jennifer Mankoff. 2012. HCI and sustainability: a tale of two motivations. *Interactions* 19, 3 (2012), 16–19.

[58] Jennifer C Mankoff, Eli Blevis, Alan Borning, Batya Friedman, Susan R Fussell, Jay Hasbrouck, Allison Woodruff, and Phoebe Sengers. 2007. Environmental sustainability and interaction. In *Extended Abstracts of the 2007 CHI Conference on Human Factors in Computing Systems*. 2121–2124.

[59] Samuel Mann, Logan Muller, Janet Davis, Claudia Roda, and Alison Young. 2010. Computing and sustainability: evaluating resources for educators. *ACM SIGCSE Bulletin* 41, 4 (2010), 144–155.

[60] Yogesh Kumar Meena, Krishna Seunarine, Deepak Ranjan Sahoo, Simon Robinson, Jennifer Pearson, Chi Zhang, Matt Carnie, Adam Pockett, Andrew Prescott, Suzanne K Thomas, et al. 2020. PV-Tiles: Towards Closely-Coupled Photovoltaic and Digital Materials for Useful, Beautiful and Sustainable Interactive Surfaces. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. 1–12.

[61] Emilie Mollenbach, Jens Hoff, and Kasper Hornbæk. 2012. HCI and sustainability: the role of macrostructures. In *CHI'12 Extended Abstracts on Human Factors in Computing Systems*. 2159–2164.

[62] Stuart Moran, Nadia Pantidi, Tom Rodden, Alan Chamberlain, Chloe Griffiths, Davide Zilli, Geoff Merrett, and Alex Rogers. 2014. Listening to the forest and its curators: lessons learnt from a bioacoustic smartphone application deployment. In *Proceedings of the 2014 CHI Conference on Human Factors in Computing Systems*. 2387–2396.

[63] Juliet Norton, Ankita Raturi, Bonnie Nardi, Sebastian Prost, Samantha McDonald, Daniel Pargman, Oliver Bates, Maria Normark, Bill Tomlinson, Nico Herbig, et al. 2017. A grand challenge for HCI: food + sustainability. *interactions* 24, 6 (2017), 50–55.

[64] Intergovernmental Panel on Climate Change. 2014. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* https://www.ipcc.ch/site/assets/uploads/2018/02/AR5_SYR_FINAL_SPM.pdf (accessed: 15 August 2021).

[65] Daniel Pargman and Barath Raghavan. 2014. Rethinking sustainability in computing: From buzzword to non-negotiable limits. In *Proceedings of the 8th Nordic Conference on Human-Computer Interaction: Fun, Fast, Foundational*. 638–647.

[66] Chris Preist, Daniela K Busse, Lisa P Nathan, and Samuel Mann. 2013. POST-SUSTAINABILITY: a CHI sustainability community workshop. In *CHI'13 Extended Abstracts on Human Factors in Computing Systems*. 3251–3254.

[67] Chris Preist, Daniel Schien, and Eli Blevis. 2016. Understanding and mitigating the effects of device and cloud service design decisions on the environmental footprint of digital infrastructure. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. 1324–1337.

[68] Chris Preist, Daniel Schien, and Paul Shabajee. 2019. Evaluating sustainable interaction design of digital services: The case of YouTube. In *Proceedings of the 2019 CHI conference on human factors in computing systems*. 1–12.

[69] Ben Purvis, Yong Mao, and Darren Robinson. 2019. Three pillars of sustainability: in search of conceptual origins. *Sustainability science* 14, 3 (2019), 681–695.

[70] Barath Raghavan, Bonnie Nardi, Sarah T Lovell, Juliet Norton, Bill Tomlinson, and Donald J Patterson. 2016. Computational agroecology: Sustainable food ecosystem design. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*. 423–435.

[71] Barath Raghavan and Daniel Pargman. 2017. Means and ends in human-computer interaction: Sustainability through disintermediation. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. 786–796.

[72] Christian Remy, Oliver Bates, Vanessa Thomas, and Elaine M Huang. 2017. The limits of evaluating sustainability. In *Proceedings of the 2017 Workshop on Computing Within Limits*. 103–110.

[73] Mohammad Rashidujjaman Rifat, Hasan Mahmud Prottoy, and Syed Ishtiaque Ahmed. 2019. The breaking hand: Skills, care, and sufferings of the hands of an electronic waste worker in Bangladesh. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. 1–14.

[74] Yvonne Rogers. 2009. The changing face of human-computer interaction in the age of ubiquitous computing. In *Symposium of the Austrian HCI and Usability Engineering Group*. Springer, 1–19.

[75] Brian Shackel. 1959. Ergonomics for a computer. *Design* 120 (1959), 36–39.

[76] Omar Shaikh, Jon Saad-Falcon, Austin P Wright, Nilaksh Das, Scott Freitas, Omar Asensio, and Duen Horng Chau. 2021. EnergyVis: Interactively Tracking and Exploring Energy Consumption for ML Models. In *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–7.

[77] Gözel Shakeri and Claire H McCallum. 2021. Envirofy your Shop: Development of a Real-time Tool to Support Eco-friendly Food Purchases Online. In *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–10.

[78] M Six Silberman. 2015. Information systems for the age of consequences. *First Monday* (2015).

[79] M Six Silberman, Lisa Nathan, Bran Knowles, Roy Bendor, Adrian Clear, Maria Håkansson, Tawanna Dillahunt, and Jennifer Mankoff. 2014. Next steps for sustainable HCI. *interactions* 21, 5 (2014), 66–69.

[80] M Six Silberman and Bill Tomlinson. 2010. Toward an ecological sensibility: tools for evaluating sustainable HCI. In *Extended Abstracts of the 2010 CHI Conference on Human Factors in Computing Systems*. 3469–3474.

[81] Stephen Snow, Awais Hameed Khan, Mashhuda Glencross, and Neil Horrocks. 2021. Neighbourhood Wattch: Using Speculative Design to Explore Values Around Curtailment and Consent in Household Energy Interactions. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–12.

[82] Robert Soden and Nate Kauffman. 2019. Infrastructuring the Imaginary: How Sea-level Rise Comes to Matter in The San Francisco Bay Area. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. 1–11.

[83] Katherine W Song and Eric Paulos. 2021. Unmaking: Enabling and Celebrating the Creative Material of Failure, Destruction, Decay, and Deformation. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–12.

[84] Yolande Strengers. 2014. Smart energy in everyday life: are you designing for resource man? *interactions* 21, 4 (2014), 24–31.

[85] Yolande AA Strengers. 2011. Designing eco-feedback systems for everyday life. In *Proceedings of the 2011 CHI Conference on Human Factors in Computing Systems*. 2135–2144.

[86] Bill Tomlinson, Donald J Patterson, Yue Pan, Eli Blevis, Bonnie Nardi, Six Silberman, Juliet Norton, and Joseph J LaViola Jr. 2012. What if sustainability doesn't work out? *Interactions* 19, 6 (2012), 50–55.

[87] Bill Tomlinson, M Six Silberman, Donald Patterson, Yue Pan, and Eli Blevis. 2012. Collapse informatics: augmenting the sustainability & ICT4D discourse in HCI. In *Proceedings of the 2012 CHI Conference on Human Factors in Computing Systems*. 655–664.

[88] Christopher Weeks, Charles Delalonde, and Chris Preist. 2014. Sustainable HCI and Encouraging Retrofitting. In *Is there a European strand of sustainable HCI?* Citeseer.

[89] Kelly Widdicks, Mike Hazas, Oliver Bates, and Adrian Friday. 2019. Streaming, multi-screens and YouTube: The new (unsustainable) ways of watching in the home. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. 1–13.

[90] Denise J Wilkins, Ruzanna Chitchyan, and Mark Levine. 2020. Peer-to-peer energy markets: Understanding the values of collective and community trading. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. 1–14.

[91] Max Willis, Julian Hanna, Enrique Encinas, and James Auger. 2020. Low Power Web: Legacy Design and the Path to Sustainable Net Futures. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems*. 1–14.

[92] Shanel Wu and Laura Devendorf. 2020. Unfabricate: Designing Smart Textiles for Disassembly. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. 1–14.