Hitting the Triple Bottom Line

Widening the HCI Approach to Sustainability

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ABSTRACT

Sustainable Development (SD) in its dimensions – environment, economy, and society – is a growing area of concern within the HCI community. This paper advances a systematic literature review on sustainability across the Sustainable Human-Computer Interaction (SHCI) body of work. The papers were classified according to the Triple Bottom Line (TBL) framework to understand how the pillars of SD play into the HCI discourse on sustainability. The economic angle was identified as a gap in SHCI literature. To meet the TBL of SD, however, a balance needs to be sought across all 'lines'. In this paper, we propose that HCI can advance the discussion and the understanding of the economic concepts around sustainability through taking a sociology perspective on the economic angle of the TBL. We sustain this claim by discussing economic concepts and the role that digital can play in redefining the established foundations of our economic system.

CCS CONCEPTS

• **Human-centered computing** → Human computer interaction (HCI); HCI theory, concepts and models.

KEYWORDS

Sustainable HCI, Triple Bottom Line, Sustainable Development, Systematic Literature Review

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1 INTRODUCTION

The concept of Sustainable Development (SD) was outlined in 1987 by the Brundtland Commission Report as the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [17]. SD represents a forward-thinking approach to sustainability and, as such, it provides a blueprint for achieving a sustainable future through the progressive transformation of both the economy and society. HCI interventions for SD are a recurring research topic in our community. The field was initially coined as "Sustainable HCI" (SHCI) in the landmark CHI 2007 conference [13, 82]. Since then, it evolved into an extensive body of work addressing the multiple perspectives related to how HCI impacts SD. The topic was founded on the premise that SD was a site for technological interventions and that pervasive digital technologies provide a platform for reflection and mediation in our future wellbeing. Blevis [13] claimed that sustainability should be a central focus in HCI and defined the core semantics of interaction design in what he named Sustainable Interaction Design (SID).

Starting from the definition of sustainability as a notion of viable futures, including the many conditions that humanity and the biosphere need in order to meet a sustainable future (environment, public health, social equality, and justice), Blevis departed from the focus on the use of resources in digital interactive technologies, to illuminate how sustainability can be applied as a critical lens to the design of these systems [13]. Dourish broadened this perspective, addressing the issues of scale in political and environmental mobilization, arguing that environmental sustainability has a significant political dimension that goes beyond contemporary HCI analysis [26]. In his words: "(we need to) *inquire into the contexts in which those practices arise, and to recognize the potential contradictions between the goals of our interventions and the forces that shape their deployment*" [26]. Knowles et al. expand on Dourish by adding that meaningful and impactful HCI interventions require a systemic perspective of scale that does not reinforce the problematic modernist/neoliberal worldview [64]. Moreover, Naomi Klein, professor of Climate Justice as well as social activist and filmmaker known for her support of ecofeminism [42], highlights the lack of reconciliation between climate change and capitalism: "the market will not produce (out of necessity or opportunity) a viable path to a sustainable future" [64]. The Climate Crisis challenges the core of our economic system's expansionist logic; hence the solutions become ideological, and we are "*locked in — politically, physically, and culturally. Only when we identify these chains do we have a chance of breaking free*" [63].

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Over time, the imperative for HCI to take a broader perspective [41, 57] has only increased to encompass critical post-humanist stances [20, 46, 51, 113] on decentering the human [21, 39, 40], in a perspective named eco-centric design/interaction [11, 91] emphasizing the role of non-humans, both as our planetary co-habitants [75] but also as the emerging semi-autonomous and autonomous systems: [2]: *"as recent developments in AI imply a new notion of what non-human sociotechnical actors might be"* [57]. In this contemporary socio technical context, the concept of "implicit interactions" [62] takes on a new relevance. These implicit interactions are of deep interest when approaching sustainability – because the significant majority of the impacts humans have on our planet's conditions reside in the background of users actions – i.e., "learning, adapting, but without explicitly interacting" [57].

Several authors [32, 37, 52] have highlighted the need for HCI and associated disciplines to address the economy in a new light. However, few papers in our corpus of analysis [14, 68, 104, 111] have fully addressed the economic angle. Building on John Elkington's 1994 [33] work on the Triple Bottom Line (TBL) that outlined the need to create an understanding and measurement of Environmental, Economic and Social impacts of corporate activities, Knowles et al. [65] proposed a Quadruple Bottom Line (QBL), which placed "economic concerns" as a fourth dimension, alongside social, personal, and environmental "lines". In their paper, they proposed examples of the type of questions that would need approaching through an economic lens, for example: "new economic models" that "adapt to one that is not based on a growth economy" or "that internalise environmental, social and spiritual impact" or even "enable the viability of local currencies". Although the QBL does include the economic angle, this framework is intrinsically different from the TBL as it accounts for a diverse understanding of sustainability – i.e., as human fulfillment. By addressing sustainability from the lens of the "radical" discourse, the authors move the focus on the condition of being human and look at the fulfillment of basic survival (environmental), social and personal needs as the core elements of sustainability, while the economic concerns "are understood to mediate our ability to satisfy these primary needs" [65].

In addition to the extremely human centered approach of the QBL, placing the economic system as the backdrop of the personal, social and environmental lines emphasizes the economic system, rather than the balance between humans, non-humans, and their environment. Moreover, the questions raised by Knowles et al. do not assist the HCI community with *how* to create/adapt a new system that is not based on a growth economy; indeed are all very different types of questions, at different scales of economic activity and from different levels of analysis that challenge the HCI community to adopt a diversified approach to their studies. Understanding the tacit interactions created by peoples' activities in an economic context, however, can add significantly to the development of viable and sustainable solutions. Through understanding those interactions from a political economy perspective – namely a balance of power –, the HCI community will be able to develop depth of understanding about the nature and context of those tacit interactions for solutions that are now not a single interface between a human and a digital technology, but a series of interactions across complex networks of human and non-human actors [106].

Scale of actions and effects was stated as one crucial entry point for design practice by Dourish [26], following Pepper's dilemmas and tensions in ecotopianism [97]. While scale has often been posited as a positive concept in our capitalist economy – with corporations, start-ups and other organizations all striving to achieve 'economies of scale', the constant search for scale – and by its implications – growth – also constitute a problem for achieving sustainable development. The dilemma of scale (e.g., "think globally, act locally" or "champion the user" while advocating for the "progressive nature of technological agendas") matches the increasing role of digital as the technology of scale making of this century. Digital technologies are themselves deeply linked with the concept of scale; all technology companies pursue scale from semiconductors all the way through to the digital platforms that users interact with every day. In addition, scale economies have been used to create our telecommunications, social media, cloud computing, and "big data" platforms – these have in turn created new types of scale – so-called "network effects"; where scale of user bases is the biggest driver – which in turn has been transformed into control over commercial domains [95] and in many cases democracy [72]. While the scale of the internet has changed the way we communicate; ubiquitous computing has transformed our understanding of spatial practice; big data has enabled understanding patterns at scale, and many other technologies are already following what represents a shift away from screen-based interactions. As the HCI scholarship adjusts from understanding scale of solutions to scale of interactions – across a more nuanced design space than just a "product" or a single user – networks of people, things and our broader environmental impact demand depth of thought about how to scale, when to scale – namely how to create appropriate scale. Here we propose integrating the economic dimension in the discourse of how we can adopt scale as a site for a productive engagement between the disciplines. Economics, in fact, has long had a tradition of understanding the primary, secondary and tertiary impacts of solutions – namely how and why things scale. Considering these concepts – through the lens of tacit interactions – will place HCI in the center of issues of creating the scale effects required to progress towards sustainable development. Expanding on Knowles et al. [64] and Nardi [90] suggestion to build on political economic concepts, we argue that delivering on the concept of scale is crucial for ensuring sustainability. Without scale, most solutions proposed cannot fully deliver on their promise of sustainability – at best they can act as illustrations or proofs of ideas.

Therefore, building on the existing HCI scholarships, we contribute to the SHCI literature by proposing how HCI can approach solutions in a manner that challenges the foundations of the capitalist, extractive economy – namely through using a political economy approach to understanding the implicit interactions that occur behind the scenes of a user's interventions. In this paper, we illustrate, through a strategic literature review, how SHCI is missing the economic angle of sustainability. We highlight that the most common approach for SD and SHCI is considering the economy as a capitalist construct, even for those that are envisioning new futures [18, 32, 35, 36]. On the other hand, expanding on [18, 32], we argue that a new series of mutually-beneficial dialogs need to be opened between HCI and economics disciplines – in particular, those economic disciplines that do not have neoclassical market theories as

their basis. Through adapting and understanding political economy aspects of power, we are able to reframe our discussions on achieving the TBL – for economics is about power – power relationships between humans, yes, but also the power of humans over the environment and the fauna and flora it contains. Through opening this dialog, we aim to assist HCI to deliver on Klein's imperative – to identify the chains of the capitalist economy and to break free of them [63] – ensuring that HCI research contributes to the design/creation of a new form of economic system that spurs the regeneration of our economies, societies/communities and indeed the biosphere that manages our climate.

2 RELATED WORK

Sustainable HCI (SHCI) started emerging as a distinct research field in 2007, with the publication of two works elaborating on the role of HCI [82] and interaction design [13] in addressing sustainability. The field has significantly evolved from these two seminal works. We have identified five systematic reviews published between 2009 and 2021 that analyze the sustainability research conducted in the areas of HCI and design [5, 25, 45, 50, 65]. In this section, we provide a summary of these reviews.

In 2009, Goodman presented the first mapping of HCI research on "environmental issues". The discourse analysis performed on 120 documents published between 1998 and 2008 led her to identify three "discourses": (i) sustainable interaction design, (ii) revisioning consumption, and (iii) citizen sensing [45]. Most importantly, Goodman pinpointed two fundamental aspects to be taken into account by SHCI researchers. First, there is no universal agreement on what an environmental problem is. Thus, building a common ground is a requirement for discussing environmental sustainability. To do so, she suggests adopting participatory design approaches. Second, sustainability and sustainable living are bound with social, financial, and governmental infrastructures. Therefore, SHCI should move from a human/user-centered perspective to a wider one.

Building on Goodman, DiSalvo and colleagues [25] analyzed and mapped the research field into five genres and identified seven axes of difference (i.e., major differences of commitment that are present even within the same genre). This two-dimensional categorization of SHCI research led the authors to identify a set of issues and key topics on which, they argue, the community should build a discussion. In particular, DiSalvo and colleagues suggested (i) widening the boundaries of SHCI by connecting with other areas and tapping into their expertise and relevant literature, and (ii) promoting debate around the internal differences that challenge SHCI scope, practices, and its very definition.

Another attempt to develop a framework to map HCI research has been made by Neris and colleagues [5]. The authors conducted a critical analysis of 51 articles and grouped them according to three categories: (i) topics, (ii) methodological approaches, and (iii) outcomes. Based on the results of this mapping, Neris and colleagues identified research gaps and listed opportunities for future research. Moreover, the authors put forward a final observation that connects to the definition of sustainability they adopted in the article – i.e., the result of a combination of three pillars (social, economic, and environmental) [17]. Specifically, they claim that the works in their corpus take into account only one dimension of sustainability, with a few exceptions (the number is not specified, though) examining two dimensions in combination, and conclude by arguing that "*research on sustainability should focus on the three pillars together*" [5].

In 2013, Knowles and colleagues published a review of sustainability research in Computing [65]. Based on the thematic analysis of 60 papers, the authors developed a holistic framework composed of questions that have motivated sustainability research in the area. The framework was then used to conduct a systematic analysis of relevant literature consisting of: (1) the top one hundred most cited papers on sustainability in computing literature (e.g., green computing, green IT, SHCI, and sustainable interaction design) published between 2002 and 2012, and (2) 122 articles published between 2010 and 2012 in the proceedings of UbiComp, Pervasive, CHI and DIS. The ten questions composing their framework were visually mapped based on a subset of broad interests they appeared to contribute to. Such a visualization was found to overlap with the structure of Triple Bottom Line (TBL). Ultimately, Knowles and colleagues elaborated a Quadruple Bottom Line framework for sustainability in computing research to account for the understanding of sustainability as human fulfillment. By taking a radical perspective to sustainability, the QBL guides research efforts toward developing solutions that target human (basic, personal, and social) *needs*, whose fulfillment is mediated by economic *concerns*. As the authors pointed out, this approach is not necessarily 'better' or 'stronger'. Rather, it represents an alternative to the reformist discourse and would lead to different solutions.

On the other hand, in more recent work, Hansson and colleagues adopt an established framework for sustainability – the UN Sustainable Development Goals (SDGs) [114] – and use it as an analytical lens to assess SHCI research. Hansson and colleagues [50] point out several advantages of mapping the SHCI research onto the SDGs. In particular, how using a globally accepted framework, such as the SDG, allows comparing SHCI to other fields. Moreover, it provides measurable indicators for evaluating current and future research. The SDGs framework was found to be useful to identify main research trends in the field of SHCI – e.g., a clear focus on pervasive technologies for behavior change – and unexplored areas. Nevertheless, limitations of the SDGs framework were also pointed out. First, Hansson and colleagues question whether the SDGs are too narrow to represent all work that can be done within SHCI. Indeed, despite dealing with sustainability issues, 20 out of 71 articles in their corpus could not be matched to any of the SDGs. Moreover, they suggest that SHCI methods may not be equally relevant to all SDGs – "(it is) *a challenge to see how HCI could substantially contribute to SDG 14, Life under water*" [50]. This remark is partially corroborated by the fact that 42 out of 51 articles were matched with 11 out of the 169 SDG targets.

The five systematic reviews described above provide interesting perspectives on the evolution of SHCI research and contributed to inspire our study. In particular, we derived the following takeaways from them:

- Sustainability is a complex issue that can be understood and consequently approached from different angles [45], even within the same community [25].

- Addressing sustainability in its social, environmental, and economic dimensions, requires a truly interdisciplinary approach [25, 45].
- The scale of actions and solutions that emerge from the economic, political, and cultural contexts are an opportunity to reconsider digital technologies as technologies of scale-making for sustainable development [26].
- In order to map and critically analyze the sustainability discourse within our community, we must adopt a solid, shared, and holistic framework [50].

Here we posit that the TBL is such a framework since it is aligned with an imaginative/reformist approach of SD, i.e., a vision that guides economic development (and technological development) in ways that are environmentally benign and socially just (another approach is ecological modernization targeting environmental damages and proclaiming economic advantages of green products and services). The TBL is therefore a way of framing and accounting for the environmental, social, and economic needs – it is about understanding the fact that humans are not solely economic beings, but rather that we must achieve a balance between what is good for the economy, broader society and also our planet. Rather than solely focusing on the human construct of economics, therefore, it places economic activity within a smaller scope, and brings home the realization that without our environment, there is no economic or social system. Unlike the QBL, the TBL better fits our understanding of sustainability, which does not focus on human needs but instead on designing the interactions between human, non-human, and technology within and across the economic, social, and environmental systems. Moreover, the TBL aligns with the concept SD outlined by the Brundtland Report as it considers environmental, social, and economic as the main dimensions of sustainability. While SD represents a forward-thinking approach toward sustainability, the TBL was designed to help examine the environmental, economic, and social impacts of an activity. Therefore, it is particularly suitable to both understand and assess the sustainability discourse within our community. The TBL has already been adopted to map and analyze existing research and demonstrated to be applicable not only to works that fall under the wide umbrella of computing research [65] but also to HCI and SHCI [5]. Finally, it provides a clear, operational, and holistic definition of sustainability, which could help direct future research.

Before describing our systematic review of SHCI literature, we briefly introduce the TBL concept to help frame it in the context of our article.

2.1 The Triple Bottom Line

As an approach to sustainability, the Triple Bottom Line was first defined by John Elkington [33]. Expanding from the concept of the "bottom line", used in business to refer to profit, the TBL provided a framework for measuring the performance of a business and success of the organization using three "lines": economic, social, and environmental [4]. The TBL expressed the expansion of the environmental agenda in a way that integrated the economic and social lines. A plethora of consultancy approaches followed the TBL concept, including corporate reporting and projects. However, recently Elkington [34] pointed out some critical problems with

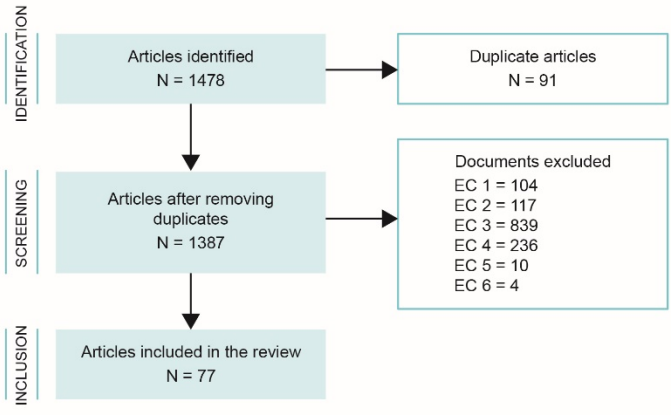

Figure 1: Identification, screening, and inclusion procedure following the PRISMA framework

the current use of the TBL approach – that the concept has been misunderstood and that too much emphasis has been placed on the financial lens itself, attempting to use the TBL to place a dollar value on sustainability, "*with the U.N. Sustainable Development Goals forecast to generate market opportunities of over $12 trillion a year by 2030*". Elkington himself, in a 25 year update of the TBL in the Harvard Business Review, outlines that the main aim of the TBL as a driver for system change in the capitalist system has been overlooked:

> "*But the TBL wasn't designed to be just an accounting tool. It was supposed to provoke deeper thinking about capitalism and its future, but many early adopters understood the concept as a balancing act, adopting a trade-off mentality. . . TBL's stated goal from the outset was system change — pushing toward the transformation of capitalism*". Elkington closes his article with a call that to "*truly shift the needle, we need a new wave of TBL innovation and deployment*" [34].

We propose that HCI and design concepts are crucial methods to assist in both the re-imagination and the re-design of economic systems with the radical intent necessary to deliver change.

3 METHODOLOGY

Through a systematic review of SHCI literature, we identified current gaps, highlighting a lack in addressing the TBL Framework [4, 33, 34] as a way to tackle the sustainability challenge in HCI. Our search strategy was based on the PRISMA Framework [94] and structured in three main phases (see Figure 1). We detail identification, exclusion criteria, and analysis procedure in the following sections.

3.1 Identification

The identification was performed according to the following criteria:

- **Database**: the analysis was focused on searching the Association for Computing Machinery (ACM) Guide to Computing Literature. This database was chosen for the quality of the

contributions and its comprehensive database in the field of computing.
- **Data filter**: the search was restricted to articles published between January 2017 and December 2021.
- **Key terms**: this review focuses on the fields of Sustainable HCI (SHCI). Therefore, we focused our query on the term "Sustainable Human-Computer-Interaction" and its abbreviations – "Sustainable HCI" and "SHCI". Sustainable Interaction Design, the term coined by Blevis [13], is described in HCI literature as a more narrow research area within SHCI [50]. We therefore conducted an additional search using the term "Sustainable Interaction Design" and its abbreviation "SID".

The database was last searched on December 19, 2021. The search resulted in 1478 items. Items with duplicate titles (91 articles) were removed before screening the remaining 1387 articles for eligibility.

3.2 Exclusion Criteria

Eligibility assessment was conducted considering the following exclusion criteria:

- **EC 1**: The item is a review article, doctoral dissertation, book, book chapter, demo, or not peer-reviewed (104 articles).
- **EC 2**: The article is not publicly available online (117 articles).
- **EC 3**: The abbreviations "SHCI" or "SID" have different meanings (839 articles).
- **EC 4**: The work presented in the article does not qualify as SHCI research (236 articles) – for example, in [48] the key term "Sustainable Human-Computer-Interaction" is used to clarify that the article is about sustainable computing and not SHCI.
- **EC 5**: Sustainability is not the main topic. Instead, it is used as an argument for discussing something else (10 articles).
- **EC 6**: The article has the same author(s), results, and methodological approach as that of another paper which was already included (4 articles).

At the end of the screening process, a total of 77 articles remained for the analysis (see Appendix 1).

3.3 Analysis Procedure

The 77 papers selected were summarized and their metadata extracted into a spreadsheet containing the article's title, author(s), publication venue and year, keywords, methods, and sustainability domain (e.g., energy, food, health), as well as a summary of the research question(s) addressed, problem setting, and main research contribution(s)/outcome(s).

Each paper was then analyzed through the following questions, to identify the targeted TBL's dimensions:

- **Q1**: Does the research target Environmental Sustainability as a central issue?
- **Q2**: Does the research target Social Sustainability as a central issue?
- **Q3**: Does the research target Economic Sustainability as a central issue?

These questions served us as a framework to determine whether the research described in the article is meant to contribute with a solution to environmental, social, and/or economic concerns. To answer them, we used a mixed approach that blends discourse [16] and content analysis [15]. In examining the corpus, particular attention was given to how the authors of the selected papers framed the research question(s) – (content analysis). When research questions were not clearly stated, we examined the description of the problem setting – i.e., the main issue(s) being addressed – and/or of the research contribution, looking at both content and language used (discourse analysis). If aspects related to one dimension were reported only as "unexpected findings" and not as part of the initial consideration of the work – e.g., participants in a user study report that economic savings are the main reason for reducing energy consumption, but the research is not meant to investigate the "economic benefit" resulting from behavior change –, then, we considered that dimension as not central. The analysis was conducted by the two first authors. Disagreements were solved by discussion.

4 RESULTS

Our screening process resulted in 77 papers that satisfied the inclusion criteria. The articles included in the corpus were mapped onto the three dimensions of SD (environmental, social, and economic). This analysis led us to identify three main trends in recent SHCI research: (i) *single bottom line approach*, (ii) *people and planet*, and (iii) *(un)sustainable economy*. The remainder of this section is divided into two parts. First, we provide a summary of the results from the mapping exercise. Second, we present and discuss the emerging trends.

As shown in Figure 2, 44 of the 77 articles included in our corpus target Environmental Sustainability as a central issue, while 15 are concerned with Social Sustainability issues. The remaining 18 articles were matched onto more than one dimension of sustainability, specifically: 14 articles focus on aspects related to both Social and Environmental Sustainability, 2 articles address the Economic and Environmental angle, one targets Economic and Social issues, and the remaining one addresses all three dimensions.

In terms of venues (see Figure 3), the most popular was CHI: ACM Conference on Human Factors in Computing Systems (20 articles), followed by DIS: ACM SIGCHI Conference on Designing Interactive Systems (12 articles), PACMHCI: Proceedings of the ACM on Human-Computer Interaction (7 articles), LIMITS: Computing within Limits (6 articles), OzCHI: The Australian Conference on Human-Computer Interaction (5 articles), C&T: Conference on Communities & Technologies - Transforming Communities (3 articles), ACM TEI: Conference on Tangible, Embedded, and Embodied Interaction (3 articles), COMPASS: ACM SIGCAS Conference on Computing and Sustainable Societies (2 articles), HCI: International BCS Human Computer Interaction Conference (2 articles), ICT4S: Conference on ICT for Sustainability (2 articles), NordiCHI: Nordic Conference on Human-Computer Interaction (2 articles), TOCHI: ACM Transactions on Computer-Human Interaction (2 articles), ACM TiiS: ACM Transactions on Interactive Intelligent Systems (1 article), CHI PLAY: ACM SIGCHI Annual Symposium on Computer-Human Interaction in Play (1 article), C&C: (1 article), C&C: Creativity and Cognition (1 article), GoodTechs: Conference on Smart Objects and Technologies for Social Good (1 article), ICCBDC: International Conference on Cloud and Big Data Computing (1 article),

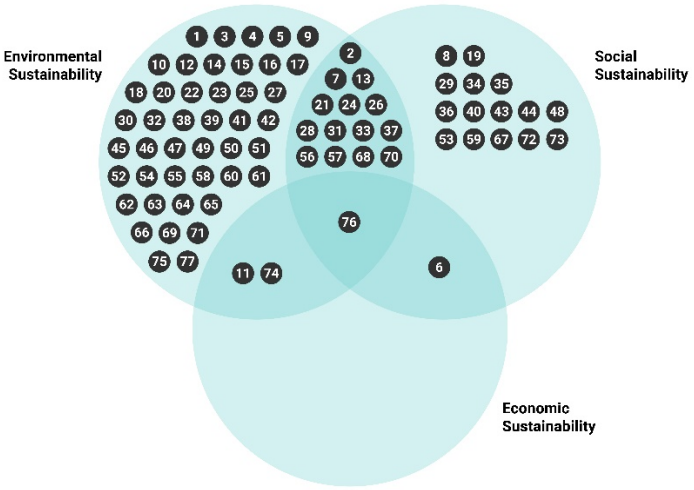

Figure 2: Distribution of the 77 papers of the corpus into the dimensions of Sustainable Development – Environmental, Social, and Economic – and their overlap. The papers are numbered according to the list presented in Annex 1.

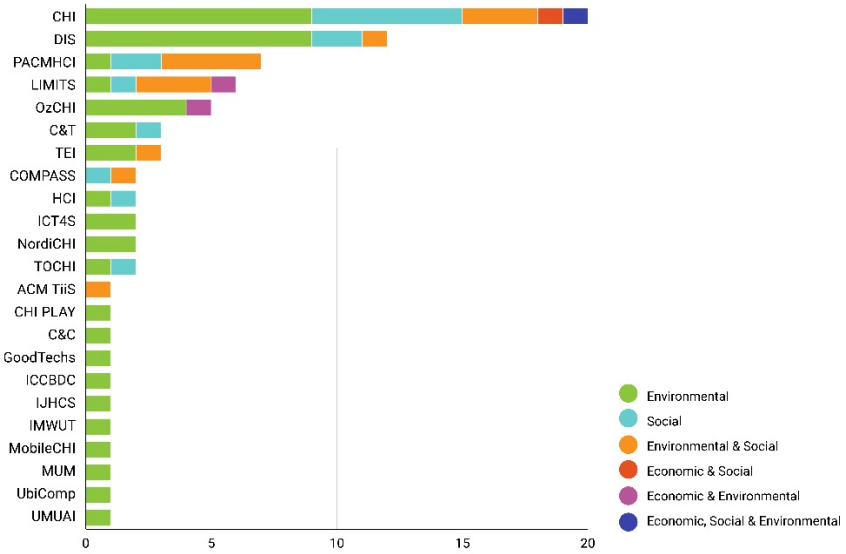

Figure 3: Distribution of the 77 papers per venue and Sustainable Development dimension explored.

IJHCS: International Journal of Human-Computer Studies (1 article), IMWUT: Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies (1 article), MobileCHI: International Conference on Human-Computer Interaction with Mobile Devices and Services (1 article), MUM: Conference on Mobile and Ubiquitous Multimedia (1 article), UbiComp: ACM International Joint Conference on Pervasive and Ubiquitous Computing (1 article), and UMUAI: User Modeling and User-Adapted Interaction (1 article).

4.1 The Single Bottom line

59 out of 77 papers in our corpus target a single dimension of SD. The majority of them (44 articles) focuses on environmental sustainability, while the remaining 15 papers are centered on the social bottom line and address a variety of topics including cultural diversity and community values (3 articles), health (2 articles), community empowerment (4 articles), practices and decent working conditions (3 articles), and housing quality (3 articles). On the other hand, the work motivated by environmental purposes (44 articles) focuses on the topic of energy (19 articles), climate change (6 articles), waste (6 articles), food production and consumption (5 articles), electric mobility (3 articles), sustainable living (2 articles), air quality (1 article), nature (1 article), and sustainable buildings (1 article).

It is important to point out that, by saying 'a single dimension', we do not mean to suggest that the other 'lines' are neglected in these papers. Regardless of the research being motivated by either environmental, social or economic purpose, several authors acknowledge the spillover benefits their work has into the other dimensions of SD. To put it simply, what emerges from our analysis is that most of the articles in our corpus take only one dimension as a central issue while treating the others as influencing factors, either positive or negative. For example, Wu and Devendorf [117] put forward an approach that integrates disassembly and reuse into the smart textiles lifecycle. The leading motivation of their work is to reduce "*the massive waste streams of both the digital electronics and textiles industries*". However, the authors do not fail to suggest the consequential economic benefit that this approach brings by highlighting how smart materials such as conductive yarns are *precious, expensive, and scarce*. Cheon end colleagues [20] developed a design intervention meant to help chefs mitigate the environmental impact of food preparation. Yet, 'cost' is reported as a relevant concern by the chefs and therefore included among the dimensions used for evaluating the recipes.

Following the classification proposed by Mankoff [82], we can further group this body of work into two main categories: *Sustainability in Design* and *Sustainability through Design. Sustainability in Design* research aims at improving sustainability of both physical products (e.g., by lowering energy use or promoting longevity, sharing, and re-use) and digital services (e.g., by limiting energy consumption and CO2 emissions of the service infrastructure). *Sustainability through Design*, on the other hand, applies HCI approaches to support sustainable lifestyles and decision-making – i.e., address sustainability as a problem domain. 9 out of 77 works in our corpus can be classified as *Sustainability in Design* research and, not surprisingly, they all tackle the environmental bottom line (4 articles dealing with energy [56, 99, 116, 118] and 5 in the domain of waste [8, 10, 34, 61, 117]). Compared to results from a previous literature review on Sustainability and HCI [5], our analysis suggests an inclination towards increasing research on this area, as called for by Mankoff [82].

4.2 People and Planet

Sustainable HCI has been witnessing a shift towards more inclusive and more diverse perspectives that propose to address sustainability through the lens of permaculture principles [27, 77] and answer the challenges of designing in the Anthropocene [39, 73, 91]. An increasing number of researchers defend a decentering of the human in design or post-humanism [40, 110]. This non-anthropocentric approach does not ignore the human factor but considers it alongside non-human voices, questioning multi-species cohabitation [2, 66, 73, 74, 81, 107, 110] and co-production [7, 21]. On a similar note, permaculture advocates that humans need to work harmoniously alongside nature, not against it, in a mutually beneficial synergy [77].

Inspired by this call, 11 articles in our corpus adopt a non-anthropocentric framework to address sustainability [12, 24, 27-29, 53, 75, 76, 78, 92, 102]. This set of papers questions the dichotomy between "us" (humans) and "them" (non-humans), stressing the need for including the non-human actors in the design for sustainability and ultimately giving them a voice [12]. In this perspective, technology becomes a means to provide an embodied learning experience of "them" [12], thus offering "us" the opportunity to blend [29], harmonize [78], and reconnect with nature [76]. This body of work posits that sustainability should be co-produced by humans, non-humans and technology, thus suggesting SHCI shifts the focus to designing hybrid spaces [53] for symbiotic encounters [78] between humans and the natural environment.

We argue that, by considering non-human actors as an integral part of the social tissue [103] – other living beings inhabiting our very same ecosystem [78] –, this body of work is blurring the boundaries between social and environmental needs. In fact, among the 10 papers that target both these bottom lines, 5 explore non-anthropocentric or more-than-human angles.

We propose that this emerging research tendency is emblematic of an important paradigm shift in the SHCI community for two reasons: 1) It widens the approach to sustainability by emphasizing the interdependency of social and environmental dimensions of SD; 2) It positions SHCI research at the intersection of these two domains and calls the community to actively serve as a bridge between social and environmental needs.

4.3 (Un)Sustainable Economy

According to the Triple Bottom Line Framework [4, 33, 34], the social, environmental, and economic dimensions are not disconnected pillars. On the contrary, they overlap and influence each other. Interestingly, our analysis suggests that the economic bottom line has received limited interest from the SHCI community. In fact, only 4 articles in our corpus have been mapped onto the economic dimension – as well as the environmental [14, 104, 111] and social [68, 104] one. In their work [14], Borning and colleagues address the way the public discourse around IT tends to hide (or even minimize) the materiality, and consequently the environmental impacts, of digital technologies. In doing so, the authors identify and discuss three main forces that more actively push toward obscuring the ecological cost of IT and ultimately put forward ideas on how to counter them. Although the spotlight is on the environmental impact of IT, this work was mapped onto the economic bottom line as well. In fact, the discussion around the economic angle is very relevant to the authors' argument as they suggest that the modern economy – which fuels consumerism and is based on the ideology of unending growth – is one of the main forces (if not the most central one) that push back from noticing materiality in IT. As a possible solution to counter this force they suggest to "let prices tell the truth" – i.e., taxing the material impact of IT so as to increase visibility. Another research that addresses both the environmental and economic lines is the one described in [111]. Motivated by the fact that high-quality feature-rich energy feedback systems are cost-prohibitive for large-scale rollout, the article puts forward a speculative, sharing economy-based model to re-think the use of such systems at a scale [111]. Results from a preliminary field deployment of the system are also provided. As acknowledged by the authors, the article describes a very early stage of the research and, at the time of their writing, several aspects yet to be prototyped. In this regard, it is important to point out that the user

study described focuses on user engagement instead of assessing 'acceptance' of such a model. Yet, we have mapped this article on the economic bottom line taking into account the main goal and underlying motivation of the research. The economic dimension is even more central in [68]. In recognizing the social and economic costs of the global food supply chain, Landwehr and colleagues look at Community Supported Agriculture (CSA) as a model for more sustainable and resilient food production systems. The authors conducted a participatory observation of a German CSA to delve into their (i) economic model based on the principle of solidarity and (ii) alternative measure of value – i.e., an alternative 'currency' which is neither a store of value nor is it a means of exchange, instead, it is merely a unit of account. By doing so, the authors highlight the potential issues with such a model when scaling up from a single CSA to an overarching cooperation structure for CSAs, and suggest ways to address them. Finally, the work described in [104] takes a broader perspective to discuss sustainability in HCI, proposing an approach that encompasses all three dimensions. Drawing on relevant work on ecological limits [96], political economy [98], and the cornucopian paradigm [31, 32], the authors put forward the design rubric of *disintermediation* – i.e., "*the removal of intermediaries while retaining the key functionality of a system – as a strategy to decrease complexity, costs, and material throughput in society*" [104]. This work not only adopts a more holistic approach towards sustainability, which includes a political economy perspective, but also attempts to provide practical direction for HCI work. The approach proposed is valuable. However, without a framework to understand the balance of power, disintermediation could lead to a rebound effect, ultimately resulting in greater inequality and environmental footprint. In fact, removing intermediaries creates a new set of interactions that happen behind the scene and need to be understood to deliver a truly sustainable solution. An example of this is blockchain technology, which allows removing intermediaries in the financial system while maintaining its functionalities, but comes at the cost of increased energy consumption.

Again, we are by no means suggesting that the economic dimension is completely excluded from the SHCI literature. As mentioned before, several authors discuss the additional (economic) benefits that their research can bring, as well as how economic factors could act as barriers to implementing the proposed solution [19, 58–60, 85, 108, 117]. What our mapping shows is an imbalance in addressing the economic bottom line, as it is not a central issue in most of the articles analyzed.

Nonetheless, by looking beyond the "quantitative" results of the mapping, we see signs of increasing interest in our (un)sustainable economy. First, we observe the SHCI commitment towards designing solutions for low-income or economically marginalized communities – for example, the residents of a deprived neighborhood [54], Global South e-waste workers [105], and low-income public housing residents [67]. Second, it is worth mentioning, once again, the limited but relevant body of work centered around the permaculture movement. By promoting a model of sustainable farming where humans work with nature instead of against it [77], permaculture catalyzes the creation of self-sufficient and environmentally sustainable communities. Thus, besides being about keeping the environmental and social engine running [77], permaculture is also *economically radical* [29]. Although research inspired by the permaculture movement may naturally tend to focus on the community-scale [93] and the very specific domain of food/agriculture [78], we believe that this emerging approach to sustainability represents an initial step towards including the economic dimension into the SHCI discourse. Finally, we note that some authors also point out the role of capital and profit-making in the current social and environmental crisis. Heitlinger et al. [53], in particular, conclude their article by arguing that our community "*must take the Anthropocene, and Capitalocene, seriously*".

We want to conclude this section in the same way we opened it: "the social, environmental and economic dimensions are not disconnected pillars. On the contrary, they overlap and influence each other". To hit the Triple Bottom Line, we must widen our approach to Sustainability and address the economy as something that can (and should) be designed, rather than a natural fact [26]. We believe that the time has come for the SHCI community to take up Knowles' call for confronting the (*(un)sustainable*) economy [64]. In the following section, we discuss possible ways for HCI to approach economic aspects in a manner that can challenge the foundations of the capitalist economy.

5 DISCUSSION AND IMPLICATIONS FOR THE HCI AND DESIGN COMMUNITIES

In order for SD projects and concepts to truly embrace the TBL, the three 'lines' need to be approached holistically. As discussed previously, the SHCI literature speaks clearly to the need of thinking about economic aspects of the TBL; nevertheless, they tend to fail to take a holistic approach.

So far, the economic angle in HCI discourse has mainly focused on two approaches:

- Framing sustainability as a component of the market economy that can be solved by informed individual choices or collective action capable of influencing patterns of consumption.
- Assuming the market is fundamentally incompatible with the climate crisis and hence we need to move to a "justice-based" economy.

The first approach veils the responsibilities and actions of other social entities, most notably corporations and states, and frames 1) regulation as a restriction on market forces and 2) corporate responsibility to return on shareholder investment, with very little involvement from government.

The latter assumes a robust set of new policies that could underpin a new economy (or economic model) with substantial government involvement in sweeping emissions and polluting activities, subsidizing green alternatives, and taxing or penalizing violations. These alternatives are firmly based on neo-classical economics, and they represent the mainstream contemporary SHCI practice. Incorporating sustainability solely in terms of personal and political dimensions of everyday consumption and choice leads to interventions primarily focused on persuasion. Considering digital technologies as infrastructures of scale-making that integrate the economic system offers new opportunities for technological design leading to a new economy. Like Dourish suggested: "*By focusing not on connecting people to their actions and their consequences, but on*

connecting people through their actions and their consequences" [26]. This means focusing on designing new politics and economics that could shape an environmental movement out of the climate crisis and not merely promoting environmentally friendly consumers.

In this paper we argue that the only way to achieve the TBL is for all three 'lines' to be approached simultaneously [33], and a robust discussion around the economic aspect of projects and solutions needs to also be considered. Several of the papers in the literature review outline that the modern economy is one of the main contributors to the environmental crises – e.g., [53]. Most of them (especially those that draw on permaculture principles) also stress the need for alternative economic models – e.g., [92]. Most of these papers, however, do not outline more than a critique of the economic system, and do not provide a robust discussion about how such a design ideology itself may 1) Impact the economic system from a broader perspective, opening the discourse to all stakeholders involved and not only members of 'small and/or marginalized communities' and 2) Provide a mechanism to challenge the underlying concepts of the capitalist system itself.

While many aspects of today's mainstream form of 'economics' – namely consumerist driven capitalism – are creating compounding effects that exacerbate environmental and social problems. This does not imply, however, that we should ignore all economic theory outright. Indeed, the notion of economics *as solely the study of market exchange mechanisms* is merely a *narrative* that has developed since the 1970s – with the global push towards deregulation and financialization unleashed during the Reagan and Thatcher eras. This narrative – or story – is one that is most understood and referred to by lay people – and other disciplines – when discussing the notion of "economic theory". There are, however, numerous other streams of economic analysis that do not place the market at the center, but rather focus on very different angles – for example, Marxist theory (which places labour at the center of its focus), Heterodox economic theory (which focuses on the interactions between the nexus of institutions–history–social structure), and even interdisciplinary approaches such as Economic Anthropology (which places humans at the center of its focus, but from a social societal perspective). Perhaps the greatest fairy-tale ever told, therefore, is the one that unless we view our economy as a series of market-based interactions – i.e., through the lens of neo-classical/capitalist economics – human society as we know it will collapse. It bears thinking through this issue briefly in order to place it into the context of this paper.

This idea that market-based economics evolved from barter economies is repeated in every economic textbook – that prior to the invention of 'money' people used barter systems to exchange goods and services with one another [46]. The story goes that if someone had two sheep and they needed a pair of shoes, they would have to negotiate an exchange – and agree a fair amount of each good to exchange with one another. Issues would arise if someone had two sheep, wanted a pair of shoes but the person with the shoes did not want or need any sheep. In that instance, a third party would need to be found that would enable the exchange of sheep for another product or service that the person with the shoes did want. The final notion of our common narrative is that because of this and other complexities, money was developed as a store of value that ensured people could freely trade with one another; i.e., that a market economy is the only assured way for humans to be able to trade goods and services with one another in an effective and efficient way. In essence, this reduces every economic 'activity' to the concept of an exchange – without the market, the story goes, we would all be reduced 'back to barter' and its shortcoming, such as dyadic negotiated exchange, as opposed to a more generalized one, such as *gifting* and *spheres of exchange* would enable [22].

The problem with this is that the idea of money developing from the 'barter economy' is a narrative that we collectively tell ourselves and are told that proves to be largely untrue; no study has ever found at any point in recorded history a barter economy of the sort outlined in all economic textbooks – either internationally or locally from the 1700s to today [46]. The world's first coins appeared in the ancient kingdom of Lydia in 600 BC, although the Mesopotamians had created a banking system in the 8th Century BC through the use of commodities as means of exchange (e.g., salt, grains, precious metals) [46]. What this highlights is that economic theory, like many other things, needs to be understood in the context in which it was written; the story of the barter economy originates from Adam Smith in his book "Wealth of Nations[1]" – the broader context of society at this time was the expansionist activities of both the nation-state and the new merchant class. Heavy misquoting of Smith through the ages has enabled the continuation of the capitalist economy. It is through releasing this creation myth of the market economy that we can break free of the chains identified by Naomi Klein and contribute to the necessity to "change the rules of our economic system, rather than the laws of nature" [63] and drive the next wave of innovation around the TBL as Elkington exhorts is necessary [34].

The authors of this paper, therefore, believe that SHCI should actively *challenge the broadly accepted narrative of economic theory* when applying the TBL and replace it with a more radical lens – a social-economic view that takes into account the political economy inherent in all systems and therefore works in synergy with natural systems and also includes non-human agents, as both more-than-human species [39, 73, 76, 78], and the emergence of an increasingly complex and fluid digital ecology, with proportion of autonomous or partially autonomous systems changing their behavior over time and with use [57]. We turn first to illustrate how SHCI can approach economic concepts, and secondly to the role that digital can play in redefining the established foundations of our economic system.

5.1 Illuminating a Path towards Sustainable Societies

Since the beginning of our history, humans have organized themselves to meet our basic needs – the material necessities of life such as food, clothing, and shelter. Traditional, neoclassical economics (NE) views all activities that a human does as the function of 'rational decision making' – often referred to as *HomoEconomicus* and places all human and company decisions as solely focused on the outcome of pleasure maximization [38]. Heterodox Economics (HE), meanwhile, rejects these notions and instead focuses on economic activity as something that happens at the nexus of institutions-history-social structure [69, 87]; it includes approaches

[1]Many claim that one of the biggest problems with the Wealth of Nations is that people have read it in isolation from Smith's other works – for example his "Theory of Moral Sentiments", we view this discussion as beyond the scope of this paper, however.

such as institutional, evolutionary, feminist, social, ecological, Austrian, Marxian, socialist and anarchist economics but one of the most important unifying aspects of HE is that many of these methods do not focus on economies as engines for growth, but rather from a distributive (both of goods and services, but also power), deliberative and ultimately as a social construct perspective [87]. Rather than draw on only one set of HE for SHCI to rely on, we instead here outline a simplified approach that will enable design and HCI disciplines to engage with the different aspects and levels of economic concepts – without necessarily becoming economics experts. In addition, we expand the concepts to include non-human participants, outlining a reformed TBL framework that expands the interaction design space to include the tacit interactions associated not just with automated devices, but with the tacit interactions associated with the selection, design and use of digital technologies by and on behalf of end-users.

Rather than *solely* as a discussion about 'exchange', economics can be more simply viewed as an organizing function – orchestrating how people produce and consume as well as exchange items with one another in a certain context. The three most basic activities in any economic system – large or small – are 1) Production, 2) Distribution / Consumption, and 3) Exchange [83]. Production and consumption are foundational elements of any type of economy – exchange does not necessarily have to be, but is commonly found in many. Surrounding production, consumption and exchange are the social, cultural, political, and institutional forces that also shape everyday decisions.

Production – involves transforming nature and raw materials into goods that are useful and/or necessary for humans. This process, however, also engages with non-human elements of our world and these aspects need to be included within our assessment. NE approaches would normally only focus on the *markets* for these inputs and for labour. HE instead takes a broader perspective, for example, ecological economics outlines the need to include flora and fauna as a key component and stakeholder in the processes of production. Furthermore, as digital technologies become increasingly embedded into the broader world technology itself starts to become a core part of the production process – not just a tool used by human workers, *but a worker in and of itself*. Understanding the broader implications of, for example, "including AI in the loop" [47, 57] will be critical for HCI to develop a complete understanding of the tacit interactions generated behind the scenes. These types of interactions spread far beyond the notion of 'ethical' or 'explainable' AI as they generate flow-on effects across labour power relations [31].

Distribution / Consumption – refers to how material goods or services are used up – for example eating food, building a house, or using energy in our homes. Again, this set of consumption processes interacts with non-human elements of our assessment. NE approaches do not consider the waste processes, nor the power imbalances between the distribution of goods, services, and the wealth required to access/consume them. On the other hand, HE is deeply interested in the so-called balance of power – between humans, nature, and increasingly machines, big data and AI themselves. Detailing how the introduction of new technologies and ecosystems affect the balance of power between actors may assist HCI in providing more robust and long-lived solutions.

Exchange – involves how goods and services are distributed among people, within the NE perspective, this often takes the view of the "market". Perhaps the most complicated of all the economic aspects, the distribution of production and consumption capacity, is in fact a cultural, political, and economic issue. Exchange is often where elements of power, control, and morality come into our economic systems and most often where people's interaction with the TBL starts and ends in a modern economic structure. For example, the exchange of money for goods or services may start on Amazon, but will have interactions all the way through to China. The tacit interactions may be experienced as a reduced economic growth locally, but these effects are hidden in the shadows of the exchange mechanism. If HCI truly wants to become SCHI it must understand those interactions.

Using Production, Consumption, and Exchange as our economic lenses, we are able to re-imagine the traditional TBL image in a similar vein to Lozano [79], who rejected the notion that Environment, Economy, and Society are separate concepts that touch only in the part of the Venn diagram where the circles overlap (see Figure 4a). We instead re-imagine the TBL as a series of deeply integrated activities, with the economy housed within society, which in turn is housed within the environment. We illustrate that the economy has a direct impact on the environment and society, while from a NE perspective the environment is viewed only as input materials. As such, it is a series of one-sided interactions or extractions from Society and Environment by the Economy.

Through applying the lenses of production, consumption, and exchange at each layer of these interactions, we enable SHCI to engage with and enact a radical transformation of the economic system – in order to do this, the normal scope of activity that the SHCI community needs to engage with needs to be expanded to include the economic realm in a deeper way (see Figure 4b). We propose that through understanding, exploring and unpacking the first, second, and third order tacit interactions across consumption, production, and exchange, SCHI will be better able to achieve its aims of genuine, long-lasting sustainable impact. We illustrate these concepts in more detail in the examples that follow.

Where interaction has traditionally been the focus of how one human or a group of humans might interact with a certain type of technology, here the notion of *interaction* is expanded to include the full set of social-economic-environmental issues – How does interaction with the technology enable different forms of economic production, consumption, and exchange? How do non-human elements interact with the economic system proposed or in place? We can clarify this as a set of first, second, and third order interactions that we need to think about when approaching solutions from the perspective of the TBL. First order interactions are related directly to the technology in question, but each of the other orders requires us to think through the broader set of stakeholders that we need to address – in particular our production, consumption, and exchange relationships between human and non-human, as well as the broader environment. Each of these orders of interaction represents distinct design views that need to be addressed when designing new economic interactions (see Figure 5).

Through expanding the boundary of interaction design using this economic lens, SHCI could assist the world in recasting how production, consumption, and exchange are conducted not just

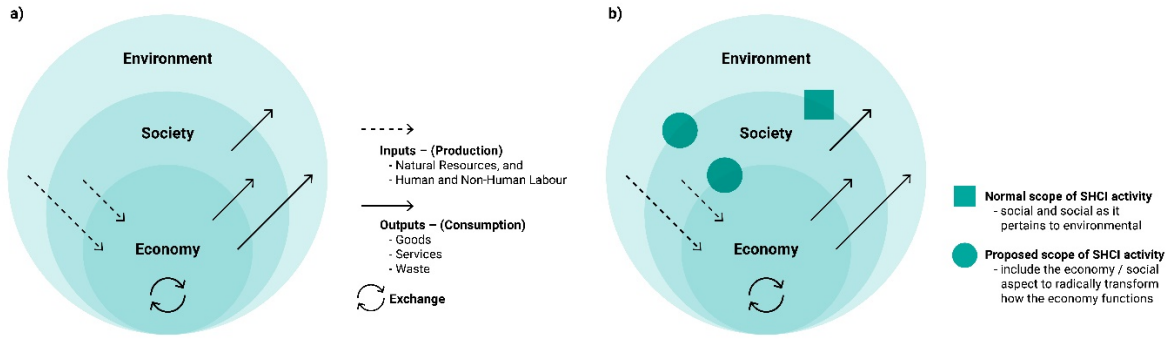

Figure 4: : (a) Re-Imagined Triple Bottom Line Framework (Adapted from Lozano [79]) (b) Proposed Expanded Scope for SHCI in Triple Bottom Line Framework (Adapted from Lozano [79]).

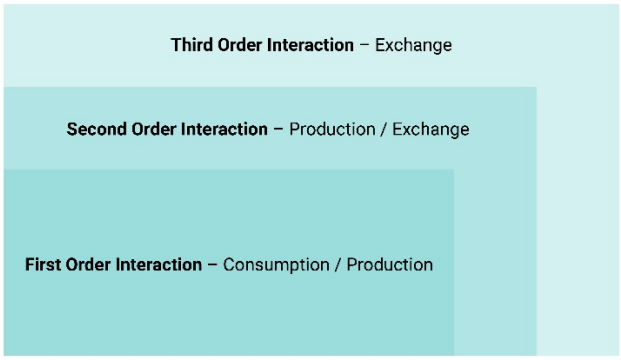

Figure 5: First, Second and Third Order Interaction Design Scopes for Sustainable Economies

within communities, but *across and between them* too. Here, we present three short illustrative examples of how these interaction spaces can be used within the HCI context. Firstly, we take the concept of developing a just, climate-neutral food system, which in many instances is studied from the perspective of the CSA or a food hub. Secondly, we look at the concept of money itself within the context of its expanding digital footprint. Finally, we look at the role of AI and automation and the creation of complex networks of humans and digital technologies.

5.2 Community Supported Agriculture

Taking CSA as an example, what does such a boundary increase look like, therefore? Instead of looking only at one CSA community, the interaction analysis could be expanded to understand how to design interactions to create second and third order effects, rather than just localized ones. In a traditional analysis, the CSA community itself would be the sole focus of activity and analysis and often from the perspective of rural communities/economies or indeed environmental protection [23].

CSA communities, however, – in particular those in Europe and the USA – are often based on ideals associated with 'organic' [23] or 'artisanal' techniques that employ 'farm to fork' or 'direct from producer' methods of production and consumption [115]. Viewed from only a first order interaction perspective, it might seem that assisting a producer to expand their customer base provides a sustainable solution and a just, climate-neutral one. While some papers talk about the supply chain, they locate it mainly from the viewpoint of the CSA itself, rather than from the entire supply chain [68] or the sole-trader in question [23] – namely looking solely at first order effects. However, if we think about the second and third order effects, we can see that in order to hit the TBL, we need to think further.

Taking a HE approach to Production, Consumption, and Exchange, however, we are able to assess the second and third order interaction impacts that need to be developed. Many CSA projects are quite elitist in their approaches with "membership composed of primarily middle to upper-income households, with few low-income individuals" [86], and do not address exclusion or justice within the supply chains [49, 115] – i.e., second and third order effects. For example, ensuring low-income earners are also able to access organic, nutritious food is not usually a goal of many CSAs or sole traders and indeed many CSAs suffer from a "paradox of exclusivity" [119].

In order to create a climate-neutral and socially just food system, therefore, these second and third order spaces of interaction need to be addressed [9]. Examples could be to redesign certain aspects of the organizational structure of the CSA to ensure farm workers are paid well while reducing the overall cost of the produce, enabling lower-income earners to be able to afford the outputs, as well as well-off consumers [10]. This requires that interventions created need to think about interactions in a new way, and perhaps more importantly use them to trigger broader effects so that individuals and companies develop new ways to engage with one another that challenge the capitalist economy. Similar techniques can assist with thinking through the unintended consequences of digital technologies more broadly.

Finally, from a third-order interaction perspective, it would be useful to address how one CSA or Food Hub might work with another CSA or Food Hub in order to create scale economies. Through combining forces, they could address the 'Exchange' interaction space, and deliver at scale. The key is that unless first, second, and third order aspects of interactions are assessed, solutions will not reach the TBL and indeed may exacerbate or delay reaching the very goals they set out to achieve.

5.3 Money: Cryptocurrencies, Blockchain and Sustainability

Another example that can be deceptively simple at first glance is money itself. Money, as we have mentioned, was previously coins and notes for several millennia. Between the 1970s and early 2000s, however, an increased level of both behind the scenes computing and automation of financial services has meant that, to a large extent, notes and coins were merely part of a digital interface metaphor (similarly to files and folders) very detached from the underlying computer-mediated transaction and networks and, more importantly, generated multiple tacit interactions to be created behind the scenes across those networks.

These implicit interactions associated with the economic system are more complex than light switches [62] or direct manipulation in WIMP interfaces so far studied within the context of HCI – in fact, we argue that many of them are tacit, that is unspoken and often not understood. Asides from the efforts in moving blockchain and cryptocurrencies to more sustainable and energy-efficient models (e.g., FairCoin[2], the notion of 'programmable money' [36], digital cash and even cryptocurrencies gain ground and commonplace acceptance [89]. HCI will therefore need to engage with these tacit interactions in a deeper way and this is what our concept attempts to address.

From a first order interaction perspective, people normally view money as the method by which a consumer pays for goods or services. As HCI engaged with the future of money and its digitalization [35] the interactions are normally studied from a first order effect perspective (similarly to personal computing paradigm) – for example how to assist people to save money or understand financial flows [71], or how the transition to digital payment systems affects work flows [101]. Again, the viewpoint is directed at the individual themselves, rather than across the whole complex set of financial interactions. As economic interactions can have profound impacts with regards to sustainable development, however, using the second and third order impacts can assist us in achieving the TBL. This would in particular be useful in the many instances that Cryptocurrencies and even Blockchain are evangelized as being able to help "solve the SDGs" [6, 55, 80, 100, 109]. Understanding the second and third order interactions therefore becomes crucial to understand the full capabilities of a new paradigm of "money technology" (e.g., notes and coins losing their physical dimensions and disappearing into the background in a transformational Weiser's perspective of a ubiquitous computing paradigm). For example, we can see that the first order effects of disintermediating the central banks created a new type of money system; however, the second order effects include increased consumption of energy for the mining rigs [120] and the third order effects of creating geopolitical impacts through the creation of the world's first global, borderless currency [88].

By taking a HE approach to Production, Consumption and Exchange we are able to assess the second and third order interaction impacts that need to be developed. Many blockchain projects focus on one of two areas: transparency and incentives creation [84]. Incentive creation is often delivered by tokenization [6], namely placing a financial value on something such as a natural resource (e.g., forests in Zööp). From a first order interaction perspective, this can seem like an excellent idea – use the economic system to deliver the outcomes that the environment needs.

If we take a step back, however, and look at the second order effects, we move beyond the interaction boundaries of "production and consumption" and can take a deeper look at the exchange effects; by placing an economic value on nature, we are – perhaps inadvertently – creating two second order interactions: 1) Creating a 'price' for services that may otherwise be invaluable or incredibly difficult to price, such as a natural ecosystem service, like the Laurisilva forest in Macaronesia[3], or landscape of the Langhe hills in Italy[4], for example, and 2) Picking 'winners' and 'losers' over who can actually make the decisions over natural resources. Through investigating these second order interactions, it is possible to think through the design interventions that can minimize these effects – for example, are cryptocurrencies effectively designed to enable interventions in the natural world?

In addition, through using tokenization, we are also creating third order interaction effects – namely the creation of a market for exchanging the tokens. In such an instance, tokenization brings a new effect – a secondary market for nature means that the value of nature itself can fluctuate based on human sentiment, rather than real-world value. In this instance, therefore, the scale effects of incentives built solely on tokenization can have large unintended consequences. Through assessing the second and third order interaction impacts, we can more effectively design solutions that manage across the three levels and ensure effective, sustainable scale.

5.4 Non-Human and more than human Solutions

Our final example briefly provides an overview of the non-human interactions associated with automation and AI. This is perhaps the

[2]https://fair-coin.org/)

[3]laurisilva natural heritage page: https://whc.unesco.org/en/list/934/

[4]Link Langhe hills natural heritage: http://whc.unesco.org/en/list/1390

area that HCI has so far placed most emphasis on understanding the role of first, second, and third order effects. Notably through the discussions on ethical and explainable AI [1, 30], and more recently connecting with computational sustainability, which has the overarching goal of developing computational models and methods to help manage the balance between environmental, economic, and societal needs for a sustainable future [43, 44]. As discussed in [47], AI-driven decision-making has led to a strong influence in some instances of ML on human-driven decision-making – "Yet insufficient research has considered how the interactions between people and models actually influence human decisions. Society lacks both clear normative principles regarding how people should collaborate with algorithms as well as robust empirical evidence about how people do collaborate with algorithms" [47]. This illustrates HCI principles being applied at first and second order interaction effects. However, through expanding these concepts to include the economic dimension – specifically the balance of power perspective – we are able to understand the tacit interactions across the domains production/consumption and exchange, namely how the interaction between human and AI creates new foundations for our economic system; one with data and algorithms at its foundation.

As research efforts in the area of AI governance are reflecting on the notion of 'digital responsibility' to account for the responsibility of economic actors [112], we would argue that the same depth of thinking needs to be applied to the economic dimension of HCI solutions and also the non-human actors most commonly found in the natural world. Haraway reminds us that the inherited concept of *anthropos* offered by liberal humanism sees "humans" in tension with each other to maintain control over the remaining earthly resources. The individualism of the liberal humanist conception of *anthropos* prevents more nuanced engagements with the world and its diverse inhabitants [50, 51]. According to post human critics Tsing [20, 113 and Alaimo [3,157], the human must be understood as a collaborator, working alongside our nonhuman planet co-habitants, enabling sustainable futures, not just for humans as some isolated and centralized feature of the planet, but for the planetary system as a whole. According to this view, our three-layered interaction framework can invite HCI practitioners to reflect on how to place the natural world at the foundation of our economic system.

5.5 Summary – A Pathway to Sustainable Economies

A key aspect of delivering these fundamental shifts in Production, Consumption, and Exchange will be the opportunities provided by digital technologies – it is the digital economy that enables the design of radically new means of interaction across all three orders of interaction. A detailed analysis is beyond the scope of this paper, however, it is a fruitful area of possible future research across – and between – all three interaction domains; when they are effectively addressed, the use of digital technologies can prove to be extremely powerful.

In summary, we are proposing a radical departure for the SHCI community in the sense that we believe that economic systems can not only be designed but that they *should* be. That it is in fact a critical area of research to explore how we can redesign our economy, illuminating the path to sustainable societies by showing that the capitalist mode of economic operation is not the only one possible. In the same way that HCI has drawn on philosophy, psychology, anthropology, and sociology, therefore, we propose that the SHCI community also draw upon the social science aspects of economics – particularly heterodox economists whose approach of dealing with the nexus of economic activity does not focus on growth, but instead focuses on deliberative and just systems to organize human activity.

6 CONCLUSION

This paper identifies a critical gap in SHCI in addressing and emphasizing the economic angle of sustainable development and the associated tacit interactions across first, second, and third order effects. As our literature review confirms, most of the contributions in SHCI have addressed the environment (planet) and society (people) with little attention to the economy (prosperity/balance of power). Hence, we call for HCI research to rebalance the triple bottom line. A consequence of the lack of concern on the economic dimension is that HCI contributions are still primarily focusing on the economy as capitalist constructs through persuasion, preventing "bad habits", promoting environmentally friendly consumers and their wellbeing in a consumerist society. While this was an important entry point for design in SHCI, it is far from the ambition required to match the increasing role of digital as one of the most important technologies of scale-making of this century to promote a sustainable economy. Here we attempt to demonstrate that a new mutually beneficial dialog needs to be opened between HCI and economics disciplines, particularly those that do not have neoclassical constructs as their basis, including but not limited to ecological economics, feminist, and Marxist traditions. Moreover, we attempt to demonstrate that the approach that HE takes – namely through understanding first, second, and third order interaction effects – enables the HCI community to broaden the scope of tacit interactions to include the extremely important notions of scale in order to achieve sustainability.

We propose that SHCI actively challenges the broadly accepted narrative of economic theory and replaces it with a more radical lens that includes those economic disciplines that embrace non-human agents and work in synergy with the broader social and political economy environment. We sustain this claim through a discussion of economic concepts and the role that digital can play in redefining the established foundations of our economic system. We illustrate the approach with three examples of how SHCI could assist the world in recasting how production, consumption, and exchange are conducted, not just within communities but across and between the boundaries as well. Firstly, developing a just, climate-neutral food system. Secondly, the role of money itself and the emerging cryptocurrency solutions proposed for sustainable development. Finally, we illustrate how fully non-human economic interactions can be captured and understood through the illustration of AI and automation.

This is a call for action for the HCI community to contribute to redesigning our economy, illuminating the path to sustainable societies and the biosphere that manages our climate.

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APPENDIX 1

Table 1: The 77 articles analyzed.

ID	Article	Venue	TBL dimension(s)
01	Ferris, et al. (2020). Melbourne 2100: Dystopian Virtual Reality to provoke civic engagement with climate change	OzCHI	Environmental
02	Hsu, et al. (2020). Smell Pittsburgh: Engaging Community Citizen Science for Air Quality	ACM TiiS	Environmental and Social
03	Biggs & Desjardins (2020). High Water Pants: Designing Embodied Environmental Speculation	CHI	Environmental
04	Xu, et al. (2019). People-centered Computing Within Limits: System Thinking on Interventions of Internet Platforms	ICCBDC	Environmental
05	Jensen, et al. (2021). Designing Eco-Feedback Systems for Communities: Interrogating a Techno-solutionist Vision for Sustainable Communal Energy	C&T	Environmental
06	Landwehr, et al. (2021). Community Supported Agriculture: The Concept of Solidarity in Mitigating Between Harvests and Needs	CHI	Social and Economic
07	Prost, et al. (2021). Contact Zones: Designing for More-than-Human Food Relations	PACMHCI	Environmental and Social
08	Cheon, et al. (2021). Jarvis in Motion: A Research Artifact for Circulating Lifestyle Values in Public	PACMHCI	Social
09	Genç, et al. (2021). KNOBIE: A Design Intervention for Supporting Chefs' Sustainable Recipe Planning Practices	TEI	Environmental
10	Hansen, et al. (2020). Lumen: A Case Study of Designing for Sustainable Energy Communities through Ambient Feedback	OzCHI	Environmental
11	Snow, et al. (2020). Rent-a-Watt: Rethinking energy use feedback	OzCHI	Environmental and Economic
12	Tai, et al. (2020). Reconnecting with Food through Dining Play	CHI PLAY	Environmental
13	Rifat, et al. (2020). Religion and Sustainability: Lessons of Sustainable Computing from Islamic Religious Communities	PACMHCI	Environmental and Social
14	Sauvé, et al. (2020). Econundrum: Visualizing the Climate Impact of Dietary Choice through a Shared Data Sculpture	DIS	Environmental
15	Liu, et al. (2020). Making Air Quality Data Meaningful: Coupling Objective Measurement with Subjective Experience through Narration	DIS	Environmental
16	Muntean, et al. (2020). Communicating Sustainable Consumption and Production in 360° Video	DIS	Environmental
17	Hill, et al. (2020). Mapping the Scope of Software Interventions for Moderate Internet Use on Mobile Devices	ICT4S	Environmental
18	Irizar-Arrieta, et al. (2020). User perspectives in the design of interactive everyday objects for sustainable behaviour	IJHCS	Environmental
19	Mitchell, et al. (2020). "No powers, man!": A Student Perspective on Designing University Smart Building Interactions	CHI	Social
20	Wu & Devendorf (2020). Unfabricate: Designing Smart Textiles for Disassembly	CHI	Environmental
21	Catelli, et al. (2020). Eco-InfoVis at Work: Role-based Eco-Visualizations for the Industrial Context	PACMHCI	Environmental and Social
22	Jensen, et al. (2019). Investigating EV Driving as Meaningful Practice	OzCHI	Environmental
23	Tuomela, et al. (2019). User values of smart home energy management system: sensory ethnography in VSD empirical investigation	MUM	Environmental
24	Norton, et al. (2019). Implications of Grassroots Sustainable Agriculture Community Values on the Design of Information Systems	PACMHCI	Environmental and Social

25	Prandi, et al. (2019). Augmenting Good Behaviour: Mixing Digital and Reality to Promote Sustainability in a Campus Community	GoodTechs	Environmental
26	Steup, et al. (2019). Feeding the World with Data: Visions of Data-Driven Farming	DIS	Environmental and Social
27	Dew & Rosner (2019). Designing with Waste: A Situated Inquiry into the Material Excess of Making	DIS	Environmental
28	Widdicks & Pargman (2019). Breaking the Cornucopian Paradigm: Towards Moderate Internet Use in Everyday Life	LIMITS	Environmental and Social
29	Heitlinger, et al. (2019). Co-Creating "Smart" Sustainable Food Futures with Urban Food Growers	C&T	Social
30	Preist, et al. (2019). Evaluating Sustainable Interaction Design of Digital Services: The Case of YouTube	CHI	Environmental
31	Liu, et al. (2019). Symbiotic Encounters: HCI and Sustainable Agriculture	CHI	Environmental and Social
32	Mauriello, et al. (2019). Thermporal: An Easy-To-Deploy Temporal Thermographic Sensor System to Support Residential Energy Audits	CHI	Environmental
33	Heitlinger, et al. (2019). The Right to the Sustainable Smart City	CHI	Environmental and Social
34	Kozubaev, et al. (2019). Spaces and Traces: Implications of Smart Technology in Public Housing	CHI	Social
35	Rifat, et al. (2019). The Breaking Hand: Skills, Care, and Sufferings of the Hands of an Electronic Waste Worker in Bangladesh	CHI	Social
36	Sultana & Ahmed (2019). Witchcraft and HCI: Morality, Modernity, and Postcolonial Computing in Rural Bangladesh	CHI	Social
37	Liu, et al. (2019). Decomposition as Design: Co-Creating (with) Natureculture	TEI	Environmental and Social
38	Lazaro, et al. (2020). Introducing the Sustainable Prototyping Life Cycle for Digital Fabrication to Designers	DIS	Environmental
39	Widdicks, et al. (2019). Streaming, Multi-Screens and YouTube: The New (Unsustainable) Ways of Watching in the Home	CHI	Environmental
40	Bettega, et al. (2021). "It's like a GPS community tool": Tactics to foster Digital Commons through Artifact Ecology	DIS	Social
41	Jones & Girouard (2021). Patching Textiles: Insights from Visible Mending Educators on Wearability, Extending the Life of Our Clothes, and Teaching Tangible Crafts	C&C	Environmental
42	Jones, et al. (2021). Punch-Sketching E-textiles: Exploring Punch Needle as a Technique for Sustainable, Accessible, and Iterative Physical Prototyping with E-textiles	TEI	Environmental
43	Søndergaard (2020). Troubling Design: A Design Program for Designing with Women's Health	TOCHI	Social
44	Kim & Li (2020). Awareness, Understanding, and Action: A Conceptual Framework of User Experiences and Expectations about Indoor Air Quality Visualizations	CHI	Social
45	Egan, et al. (2019). The Lions' Gate: Towards a Permaculture-inspired Blended Space	LIMITS	Environmental
46	Rivera, et al. (2020). Diminishing space-peer-to-peer sharing as a transition practice	ICT4S	Environmental
47	Meurer, et al. (2019). Opportunities for Sustainable Mobility: Re-thinking Eco-feedback from a Citizen's Perspective	C&T	Environmental
48	Rashed, et al. (2021). Pandemic, Repair, and Resilience: Coping with Technology Breakdown during COVID-19	COMPASS	Social
49	Steup, et al. (2018). Growing tiny publics: small farmers' social movement strategies	PACMHCI	Environmental
50	Jensen, et al. (2018). Assisted shifting of electricity use: a long-term study of managing residential heating	TOCHI	Environmental
51	Hasselqvist & Eriksson (2018). Designing for diverse stakeholder engagement in resource-intensive practices	NordiCHI	Environmental

52	Svangren, et al. (2018). Driving on sunshine: aligning electric vehicle charging and household electricity production	NordiCHI	Environmental
53	Prandi, et al. (2018). On exploring a pervasive infrastructure to foster citizens participation and sustainable development	HCI	Social
54	Jensen, et al. (2018). Washing with the Wind: A Study of Scripting towards Sustainability	DIS	Environmental
55	Herbig, et al. (2018). Design Guidelines for Assistance Systems Supporting Sustainable Purchase Decisions	DIS	Environmental
56	Muralikumar & Nardi (2018). Addressing limits through tracking food	LIMITS	Environmental and Social
57	Kuznetsov & Tomitsch (2018). A study of urban heat: Understanding the challenges and opportunities for addressing wicked problems in HCI	CHI	Environmental and Social
58	Promann (2018). Examining the Role Visual Graph Structures Play in Collective Awareness and Cooperative Decisions	CHI	Environmental
59	Mitchell Finnigan, et al. (2018). SpaceBot: Towards Participatory Evaluation of Smart Buildings	CHI	Social
60	Jensen, et al. (2018). Designing the desirable smart home: A study of household experiences and energy consumption impacts	CHI	Environmental
61	Liu, et al. (2018). Design for collaborative survival: An inquiry into human-fungi relationships	CHI	Environmental
62	Mogles, et al. (2018). A computational model for designing energy behaviour change interventions	UMUAI	Environmental
63	Rasmussen, et al. (2017). Exploring the flexibility of everyday practices for shifting energy consumption through clockcast	OzCHI	Environmental
64	Mauriello, et al. (2017). A temporal thermography system for supporting longitudinal building energy audits	UbiComp	Environmental
65	Wang & Fussell (2017). EnergyHome: leveraging housemate dynamics to motivate energy conservation	MobileHCI	Environmental
66	Egan, et al. (2017). Permaculture as a foundation for sustainable interaction design and UX	HCI	Environmental
67	Wong-Villacres, et al. (2021). Reflections on Assets-Based Design: A Journey Towards A Collective of Assets-Based Thinkers	PACMHCI	Social
68	Blevis, et al. (2017). Further connecting sustainable interaction design with sustainable digital infrastructure design	LIMITS	Environmental and Social
69	Egan & Benyon (2017). Sustainable HCI: Blending permaculture and user-experience	DIS	Environmental
70	Wyche, et al. (2018). Defamiliarizing the Domestic: Exploring" M-Kopa Solar" and Sustainable Practices in Rural Kenyan Households	COMPASS	Environmental and Social
71	Baytaş, et al. (2018). Towards materials for computational heirlooms: Blockchains and wristwatches	DIS	Environmental
72	Okerlund, et al. (2018). Statement Making: A maker fashion show foregrounding feminism, gender, and transdisciplinarity	DIS	Social
73	Bates & Friday (2018). Intangible commodities with free delivery: Finding the limit in digitally mediated e-commerce and workforce injustice	LIMITS	Social
74	Borning, et al. (2018). What pushes back from considering materiality in IT?	LIMITS	Environmental and Economic
75	Finnigan, et al. (2017). Augmenting audits: Exploring the role of sensor toolkits in sustainable buildings management	IMWUT	Environmental
76	Raghavan & Pargman (2017). Means and ends in human-computer interaction: Sustainability through disintermediation	CHI	Environmental, Social, and Economic
77	Verma, et al. (2017). Studying space use: bringing HCI tools to architectural projects	CHI	Environmental