ICT under Constraint: Exposing Tensions in Collaboratively Prioritising ICT Innovation for Climate Targets

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The international treaty known as the Paris Agreement requires global greenhouse gas emissions to decrease at a pace that will limit global warming to 1.5 degrees Celsius. Given the pressure on all sectors to reduce their emissions to meet this target, the Information Communication Technology (ICT) sector must begin to explore how to innovate under constraint for the first time. This could mean facing the unprecedented dilemma of having to choose between innovations, in which case the community will need to develop processes for making collective decisions regarding which innovations are most deserving of their carbon costs. In this article, we expose tensions in collaboratively prioritising ICT innovation under constraints and discuss the considerations and approaches the ICT sector may require to make such decisions effectively across the sector. This opens up a new area of research where we envision HCI expertise can inform and resolve such tensions for values-based and target-led ICT innovation toward a sustainable future.

CCS Concepts: • **Human-centered computing → Empirical studies in HCI**;

Additional Key Words and Phrases: ICT innovation, ICT sector, researchers, technologists, prioritisation, sustainable HCI, SHCI, climate change, climate emergency, environmental sustainability, Paris Agreement

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1 INTRODUCTION

The catastrophic consequences of climate change are becoming ever more apparent [63]. World leaders have committed to the Paris Agreement: a guiding framework for nations to ensure a maximum of 1.5°C of global warming. Yet meeting its targets requires significant emissions reductions both immediately and into the future—specifically, global net zero emissions by 2050 at the latest. To meet Paris targets, nations will require that *all* sectors in the global economy reduce their carbon footprint—with implications for **Information Communication Technology (ICT)**, both in terms of its own climate footprint [33], and its possible role in decarbonisation of other sectors [38].

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This raises important questions for the ICT sector: Should ICT be allowed to grow and innovate freely for its stated (but largely unevidenced) role in addressing climate challenges? If not, then what innovation can we afford, for what value to society, and who gets to decide?

ICT devices, data centres and networks all have an environmental impact through the energy they use directly but also significantly via the embodied emissions of producing the technology and its end of life disposal. Estimations of the total carbon footprint of ICT vary between experts [2, 8, 57] from 1.8% to 2.8% of global greenhouse gas emissions [33]. Some suggest this impact could increase further to 4–5% of global emissions [1], yet more optimistic projections suggest emissions could instead be halved by 2030 [56]. Despite these conflicting estimates, historic patterns show ICT's emissions have continuously risen, and all these experts believe ICT's environmental impact will not reduce without a concerted political and industrial effort [33]. If we assume ICT's impacts will simply stabilise, then the ICT sector would still need to reduce its carbon footprint by 42% by 2030, 72% by 2040, and 91% by 2050 to be aligned with the Paris accord, and while increases in energy efficiency and adoption of renewable energy sources will help this endeavour, they alone could not be relied upon to enable such extensive emissions reductions [33]. In fact, recent work calls for a constraint on ICT's emissions to avoid efficiency-based solutions from currently increasing ICT demand and thus offsetting emissions savings or, in the worst case, increasing ICT's emissions overall [85].

ICT's environmental impacts are well known in research communities such as **Sustainable Human-Computer Interaction (SHCI)**, with efforts looking to expose these impacts and reduce their severity through interaction design [4, 12, 13, 69, 83]. SHCI work has also often focused on how ICT can promote sustainability [27, 37, 50], yet such design research has not supported anywhere near the vast carbon savings we need to address the climate emergency [48] despite calls for more radical, activist, and political approaches [29, 49, 79]. While we would not of course suggest it is the role of SHCI or even ICT alone to address such a global challenge, we argue it is no longer acceptable simply to adapt designs to be "more sustainable" while tolerating continued technology growth. Rather, this trajectory needs to be *reversed*, with the ICT sector needing to make stark decisions on what (limited) ICT innovation it should prioritise under climate constraints. Thus, we instead propose using HCI expertise as a mechanism to expose tensions in prioritising ICT collaboratively and offer ways forward for HCI to support the ICT sector in resolving these tensions through values-based and target-led ICT innovation for a sustainable future.

In this article, we use an exploratory participatory exercise to begin to explore some of these tensions—uncovering influences, interpretations, and considerations for priority decision-making in ICT innovation.[1] Through this, we uncover what evidence, context, and digital tools the sector may require to be able to make collective choices regarding which valued applications of ICT to continue—*instead of* other valued areas of ICT—in a carbon-constrained world. Our goal is *not* to arrive at a concrete prioritisation for global ICT innovation or to hint at areas undeserving of their carbon impacts. Rather, our goal is to observe participants' decision-making processes to *expose the thorny challenges entailed in such decision-making*. We discuss issues regarding who, what, where, and how we should make decisions to effectively prioritise ICT innovation collectively and outline implications and future HCI research to support the ICT sector in exposing and resolving tensions for prioritising ICT innovation in line with Paris targets.

[1] In this article, we take the definition that "innovation" is "the introduction of new things, ideas or ways of doing something" [64]; thus this incorporates future novel ICT, as well as the current use and development digital technologies that need to be sustainably innovated within the climate crisis.

2 RELATED WORK

ICT research communities have formed various and interlinking pathways that address environmental challenges and ICT's role within this. Examples include considering sustainability within the development of ICT through sustainable software engineering (e.g., References [7, 73]), developing methodologies and assessments for the carbon impacts of ICT (e.g., References [9, 23]) (i.e., green ICT literature [44]), and using ICT for responding to challenges in environmental science through environmental informatics [34, 44, 68]. The SHCI community has also been a significantly contributing domain to the topic of ICT and environmental sustainability since its establishment in 2007. SHCI takes a more socio-technical and interdisciplinary approach to sustainability, exploring the interactions between humans, ICT, the environment, and the responsibility of ICT design for sustainable futures; given this focus and its methodological approaches, SHCI provides an effective framing for exploring tensions in collaboratively prioritising ICT.

As an overview of this area, SHCI researchers have been investigating how ICT can be designed to minimise its environment impacts (sustainability *in* design [58]) or be applied to make other activities more sustainable (sustainability *through* design [58]). For sustainability in design, research has explored the environmental impact of ICT [4, 55, 70, 83], addressing device obsolescence [71] and offering principles for sustainable interaction design [12, 13]. In sustainability through design, research has included the following: making resource consumption more visible to users with the hope of reducing this consumption, e.g., for energy and water [52, 76]; utilising dystopian Virtual Reality to engage citizens with climate change and promote pro-environmental behaviour [31]; exploring the role of contextual food data [54] and self-tracking technologies [22] to encourage sustainable food practices; and the development of information systems for sustainable communities, with calls for such services to better embody these communities' values within their design [62].

While this work has merit, there have been several critiques of SHCI that suggest a need to broaden its focus beyond individual behaviour [17, 48], with Knowles et al. highlighting that SHCI focuses too much on *"minimal impact"* solutions that fall far short of what is required by the climate emergency [49, p. 3593]. Rethinking SHCI, Baumer and Silberman [6] propose that sometimes it may be best *not* to design, e.g., if a non-tech solution is more appropriate or if the ICT does more harm than good. Similarly, Pierce [66] introduced the concept of *undesign*, suggesting that there is opportunity for HCI designers to negate ICT by its own design. Moreover, while there have been suggestions for SHCI and "ICT for Development" communities to create ICT that help people prepare and adapt to political, social, or ecological change (e.g., from climate change) through collapse informatics [80], there have been brief mentions of *removing* ICT to prepare people for collapse scenarios where the ICT may no longer be able to function [81].

Adding to these critiques, Hansson et al. [43] have recently investigated how SHCI research maps to the United Nations' **Sustainable Development Goals (SDGs)** [61]—finding that for the majority of papers that *do* map to the SDGs, they focus on SDG 12, "Responsible Consumption and Production," and only 2 of their total 71 paper corpus linked to the SDG, "Climate Action." This is despite the urgency of the climate crisis and calls for SHCI to orient around climate change [48]. Thomas et al. [79] also point out that SHCI does not directly respond to climate change policies or goals, yet ICT4S research by Pargman et al. [65, p. 293] argues that the *"concrete nature"* of carbon emission reduction targets (specifically the "carbon law") can aid a trajectory for any sector, society, or time span toward Paris Agreement goals. From recently reviewing SHCI research, Bremer et al. [16] suggest a shift in focus for SHCI toward *"Green Policy Informatics,"* enabling the community to develop digital systems that support climate policies.

In this article, we directly respond to SHCI's critiques and ICT's role in the climate crisis and explore a new way in which HCI can promote political action, shape computing outputs, and support climate policies (cf. References [16, 48]): By using a HCI-based exercise to expose the tensions and considerations in collaboratively making decisions on priorities for ICT innovation. With this as a focus, we do not aim to establish prioritisation decisions on ICT innovation but rather explore the role of HCI in exposing tensions in such decision-making that the ICT sector needs and uncover how HCI can support the ICT sector in resolving these tensions as it aligns with the Paris Agreement. While prioritisation has been investigated for broader energy research (e.g., identifying priority research questions for energy in cities [59] or UK energy system changes to support low-carbon business models [42]), to the best of our knowledge, this is the first study that considers the topic of prioritising innovation in ICT, what tensions exist in such decision-making, and specifically HCI's role in exposing and resolving these tensions for ICT's sustainable future.

3 METHOD AND PARTICIPANTS

We designed an exploratory participatory HCI study to investigate how ICT researchers and technologists prioritise ICT innovation as a means of prompting structured reflection about the tensions that the ICT sector would need to consider in making priority decisions regarding strategic cuts to its carbon footprint.[2] This involved 20 ICT researchers and technologists[3] engaging in a "prioritisation exercise" in pair-based interviews via Teams. By offering this practical exercise as experience of prioritising ICT innovation, we were able to uncover the tensions in such processes and discuss these in-depth with the participants themselves through the interview questions. The study was ethically approved and participants were informed that the study was motivated by environmental sustainability, noting the need to mitigate ICT's carbon footprint and to understand what valued ICT innovation people believe we should prioritise and continue under constraints on ICT growth.

Each participant was asked to answer a pre-interview demographic survey covering their age, gender, employment status, highest education level, primary sector of work (academia, industry, or equally both) and their familiarity or past experience of working with notable ICT trends. Participants were recruited via email advertisement and snowballing methods, were required to work or have worked as an ICT researcher or technologist, and were offered a £10 voucher. Studies were conducted in September–December 2020[4] at a time to suit participants. The participants are summarised in Table 1—ranging from 20s–50s in age, 50% female and 50% male,[5] with a variety of industry or academic experience. Participants were well educated, with 14/20 holding a postgraduate degree and all having engaged in further education; this was not explicitly a design of the study recruitment but as a result of snowball sampling.

The interview involved an ice breaker exercise for the participants to introduce themselves and denote what they believe are ICT's key strengths and weaknesses,[6] the "prioritisation exercise," followed by a round of discussion questions. The prioritisation exercise involved displaying a grid via video link of 12 broad categories of where ICT is applied: Natural Sciences; Energy; Manufacturing; Logistics and Transport; Society and Community; Education and Skills Development; Health, Medicine and Psychology; Security, Privacy and Defence; Government, Policy and Law;

[2]We focused on participants with this career demographic given individuals with these roles will have expertise in ICT; however, in our discussion (e.g., see Section 5.1) and implications, we explore the question of *who* should make decisions regarding ICT prioritisation beyond this expert group.
[3]We recognise our study had a small sample size, yet this is not uncommon for HCI research [19] and is appropriate for exploratory studies such as this.
[4]The study was conducted during the global Covid-19 pandemic, which impacted the study results (e.g., see Section 4.1.3).
[5]We have since recognised that "female" and "male" are sex, not gender, but display the original data. Participants only identified as binary genders.
[6]Group 7 did not do the ice breaker exercise as they had limited time to participate and already knew each other.

Table 1. Participant Summary

G#	P#	Age	Gender	Occupation	Sector	Top qualification
G1	P1	30s	Female	Lecturer	Academia	Doctorate
G1	P2	40s	Female	Lecturer	Academia	Doctorate
G2	P3	30s	Female	Researcher	Academia	Doctorate
G2	P4	40s	Male	Company Director	Both	Doctorate
G3	P5	30s	Female	PhD Student	Academia	UG Degree
G3	P6	30s	Male	Researcher	Academia	Doctorate
G4	P7	30s	Female	PhD Student	Both	Master's Degree
G4	P8	20s	Female	Researcher	Academia	Master's Degree
G5	P9	20s	Female	Engineer	Industry	UG Degree
G5	P10	20s	Male	Researcher	Both	Doctorate
G6	P11	40s	Male	Professor	Academia	Doctorate
G6	P12	30s	Female	Researcher	Industry	Doctorate
G7	P13	30s	Male	Engineer	Industry	Master's Degree
G7	P14	30s	Male	Lead Engineer	Industry	Sixth Form/ College
G8	P15	20s	Female	Analyst/ PhD Student	Industry	UG Degree
G8	P16	40s	Male	Academic	Academia	Master's Degree
G9	P17	30s	Male	Senior Researcher	Academia	Doctorate
G9	P18	50s	Female	Professor	Academia	Doctorate
G10	P19	20s	Male	PhD Student	Both	UG Degree
G10	P20	20s	Male	Researcher	Both	UG Degree

Participants chose the sector (industry, academia, both equally) they felt they work, or have worked, mostly in. For age, "20s" for example classes as 20–29 years old, protecting participants' anonymity. UG is an acronym for undergraduate.

Business and Commerce; Entertainment and Fitness; and Robotics. The researcher provided participants with examples of the type of ICT innovation that may occur in each category, noting that ICT may be used to enhance these categories (e.g., for "Natural Sciences," using ICT to monitor the natural environment) or that these categories may be used to enhance ICT (e.g., for "Natural Sciences," creating new materials for ICT development).

Participants were then asked to individually allocate 12 "tokens" to represent what categories of ICT application they believe should be prioritised, exploring what areas of ICT application they deem to be most important and valuable to continue under constraints on ICT innovation. Tokens were used to broadly represent resources put toward those categories (e.g., money, environmental, or workforce resources); 12 tokens were provided so at least 1 token could be allocated to each category, but participants were able to distribute these as they wished (e.g., three on four categories). The participants were asked to describe how they allocated the tokens; the researcher placed their tokens on the grid.

To simulate the requirement to ratchet down emissions over time in line with increasingly ambitious interim targets, the participants were then asked to allocate 12 tokens as a group—discussing their decisions throughout the task. This was then repeated with a depleting number of tokens: nine tokens (75% of total), 6 tokens (50%), 3 tokens (25%), and, finally, one token to identify their most prioritised application domain. Like the individual exercise, participants were prioritising what ICT they deem most important and valuable to continue under constraints on ICT innovation.

The researcher observed the study, taking frequent photos of the application categories grid to record the participants' priorities, as well as answering any questions or prompting engagement.

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20
Natural Sciences	1	0	0	2	1	2	2	2	1	1	0	1	0	0	1	1	1	0	1	0
Energy	2	0	3	1	2	1	0	0	3	2	1	0	2	1	3	3	2	2	1	1
Manufacturing	0	0	1	0	0	1	0	0	0	1	0	0	2	2	0	0	0	0	1	0
Logistics and Transport	1	0	1	0	0	1	0	0	1	0	2	1	2	0	0	1	1	1	1	0
Society and Community	2	0	2	1	1	1	2	1	0	0	0	3	2	1	3	1	3	2	1	4
Education and Skills Development	2	4	1	3	2	1	1	4	2	3	1	1	2	3	1	2	1	2	1	3
Health, Medicine and Psychology	2	2	2	0	2	2	3	4	2	2	1	1	0	1	2	2	1	2	1	3
Security, Privacy and Defence	0	2	1	1	2	1	0	0	2	1	2	0	2	2	0	0	1	2	1	1
Government, Policy and Law	2	2	1	2	2	0	0	1	1	0	3	0	0	2	1	1	2	1	1	0
Business and Commerce	0	1	0	1	0	1	1	0	0	0	0	1	0	0	0	0	0	0	1	0
Entertainment and Fitness	0	1	0	0	0	0	0	0	0	1	0	1	0	0	1	1	0	0	1	0
Robotics	0	0	0	1	0	1	3	0	0	1	2	3	0	0	0	0	0	0	1	0

Fig. 1. A heat map of the participants' individual prioritisation by ICT application category. Numbers represent the number of tokens allocated to the ICT application category; darker squares represent more tokens.

Discussion questions followed around feedback on the study alongside the participants' thoughts on how the ICT sector could make collective priority decisions.

Following each interview, the researcher textually recorded the priority decisions from the photos to visualise how priorities changed during the exercise and compared to other groups; and fully transcribed and analysed the audio recordings, using thematic analysis (cf. Reference [15]). Themes were re-coded as each interview was conducted until findings converged; final themes were discussed with another researcher to ensure the coding was an appropriate representation of how participants approached the decision-making, as well as the tensions and considerations in their prioritisation.

A note on categories used in the prioritisation exercise: The 12 categories of ICT application were created by a preliminary analysis of data from the UKRI's GtR,[7] a publicly available database containing information about UK Government funded research. This specifically involved analysing 102 digital technology projects associated with major trends that have been noted for their significant energy impact [33]: Data Science and **Artificial Intelligence (AI)**, the **Internet of Things (IoT)**, and Blockchain. We recognise there are limitations in asking our participants to prioritise global ICT innovation based on analysis from a subset of UK-funded projects; however, our focus was on understanding how participants approach decisions rather than the prioritisation outcomes made by participants. We are not making any claims for global ICT prioritisation based on the participant decisions, and the exploratory method is instead used to uncover complexities in decision-making for ICT innovation. In that notion, we could have perhaps even replaced these 12 with a different set of categories, leading to different decision outcomes yet similar challenges for decision-making approaches and influences and HCI's role in ICT prioritisation. Nevertheless, we provide all details regarding the analysis and formation for the 12 categories as supplementary material for transparency.

4 FINDINGS

4.1 Influences on Participants' Priorities

When forming priorities (Figures 1 and 2), the participants discussed various influences that impacted their decisions, including their role and expertise, personal and cultural values, and the salience of world events on their thinking.

[7]UKRI (UK Research and Innovation) GtR (Gateway to Research): https://gtr.ukri.org/

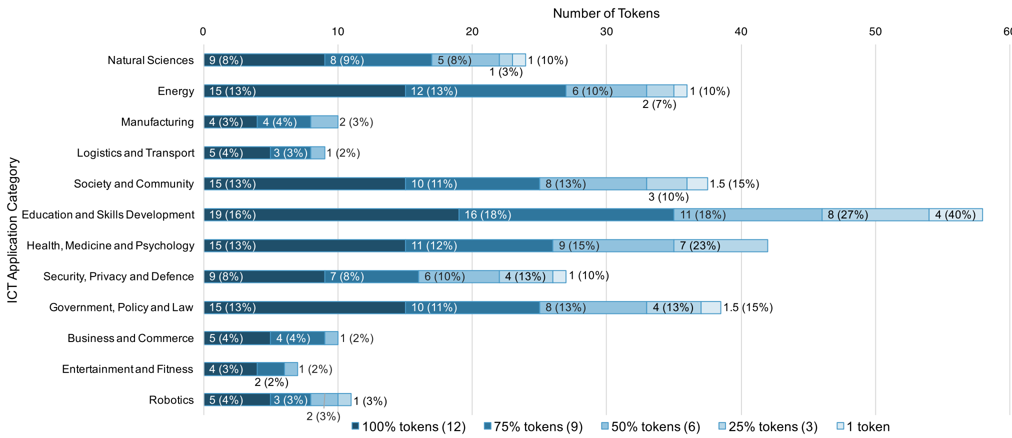

Fig. 2. The participants' group prioritisation as tokens depleted during prioritisation rounds. Data labels represent the total number of tokens allocated and their percentage (to nearest whole percentage) of tokens for that round. Note that G6 could not make a decision on their final grouping and so 0.5 tokens were allocated to the two groups they could not choose among Society and Community, and Government, Policy and Law.

4.1.1 Work Roles and Expertise. The participants often referred to an experience during their working life in justifying the rationale for their allocation. This usually resulted in acknowledgement of a positive bias toward their own research expertise or knowledge of a particular application domain. For example, P2 suggested more resources are needed within "Government, Policy and Law" due to her work on women's harassment via ICT; P8 stressed the importance of using technology for mental health given her work in the area; and P14 discussed how issues regarding a lack of human consideration in a prior project led to his allocations on the "Society and Community" theme. Similarly, decisions were linked to the sector they were working in (P6, P15–16, and P18), or their knowledge of specific technology (P16 and P19), ICT job gaps (P6) and ICT funding bodies' priorities (P17). Participants sometimes reflected on such work biases (P7, P14, and P17), and the focus on ICT occupations in our participant sample shows how these ICT-specific work roles and expertise influence their decisions; further work would be required to explore the impact of other work roles and expertise from participants with varying occupations (discussed further in Section 5.1).

Work colleagues or collaborations also influenced these decisions: G2 discussed how working with ICT researchers and companies had emphasised a need for technology to be regulated; both P16 and P18's work with others, e.g., through consultancy or committee membership influenced their decisions; and P5 discussed how she's learned more about security and health from other researchers during her teaching roles, impacting her token allocation.

4.1.2 Personal and Cultural Values. Participants drew on their own personal or cultural values throughout the group interviews. These included being people or family orientated (P3, P5, P8, and P15) and considering where society as whole could most benefit from ICT prioritisation (P5 and P12), being sustainability orientated (P4, P5–8, and P20) or considering other life forms, e.g., animals (P7), and having country or community perspectives (P4, P9, P12, and P17), such as the different needs of developing countries in comparison to developed countries (P2 and P7–8). These values were clearly influencing their decisions, with half of the participants' language indicating this (P3–6, P8–11, and P19–20). To share just a few examples of this: "that [theme] isn't pulling at the heart strings as it were" (P3); "it's like really, really important to me" (P4); "I wouldn't say that ‘Security, Privacy and Defence’ is like my passion” (P5); “there’s some grids that I’m strongly against” (P8); “that’s selfishly not important to me” (P15); and “that one is quite close to my heart” (P17). P6 and P16 also explicitly reflected that prioritisation decisions come down to one’s values and beliefs, and some participants mentioned specific ICT companies that aligned, or conflicted, with their values (e.g., Tesla and Facebook).

4.1.3 Current Events. Participants often referred to current events when making their decisions and justifying them. These included the environmental crisis and sustainability (P13–14 and P16–19), U.S. elections (P5 and P12) and the Cambridge Analytica scandal (P9 and P11), the digital divide or skills gap (P4–5, P8, P12–14, and P17–18), and current privacy, justice or security issues (P4, P6, P17, and P19). Most prominently, and likely due to this study being run during the pandemic, Covid-19 was brought up as a defining reason—with 17 of the 20 participants mentioning the health crisis in some way. This included the relevance of health through pandemic monitoring and remote medical support (P2, P6, P15, P17–18, and P20); the importance of entertainment for fun and mental health (P1–2, P12, and P15–16); being in contact with others and avoiding isolation (P3–4, P15, and P18–19); enabling online education and work (P5, P10, P12, and P20); and supporting e-commerce and goods logistics, including vaccines (P9, P11, and P18–19). Some participants also mentioned media impacted their decisions, such as the “Social Dilemma” Netflix documentary on privacy (P5–6 and P8) and the David Attenborough films on environmental sustainability (P15 and P18). Two participants explicitly reflected on how their choices were being defined by “what’s happening in the world in the moment” (P15) or “influenced by the current state of affairs” (P10).

4.2 Participants’ Interpretations

It became clear that the participants brought their own interpretation of the meaning of the themes and categories we chose for the prioritisation exercise, including ICT’s role within the themes, and the goal of the prioritisation itself.

4.2.1 Interpretations of Themes. P3 clarified she allocated tokens to “Security, Privacy and Defence” on the basis of keeping technology secure, rather than, by way of counter-example, using AI for Defence. P15 mentioned how she allocated tokens to “Entertainment and Fitness” because of its benefits to mental health, and P4 discussed how his allocation to “Business and Commerce” was due to his perception that the theme is responsible for the majority of innovation and uptake of emerging technology. These interpretations of the themes were no doubt impacted by the participants’ influences (Section 4.1).

Seventeen participants felt the themes overlapped, with some finding it difficult to differentiate some themes at all (e.g., P4: the interplay between “Energy” and “Logistics and Transport”; P7: “Health, Medicine and Psychology” and “Robotics”), as P4 describes: “these different cells here, they’re very much meta cells, like if there was a Venn diagram, they cross very strongly over each other.” In G6, the participants’ interpretations meant they were potentially referring to identical ICT applications despite choosing different themes, with P11 noting that “at a very simplistic level, all those boxes could be mutually exclusive but they can’t be [...]I guess one reason they can’t be is probably ICT.” Moreover, participants discussed how there were overarching themes, such as society (P2, P18, and P19), e.g., “I personally would title that entire grid as society” (P19), or the environment and society (P5, P6, and P10). Given these overlaps, participants made prioritisation decisions on the basis that removing a token from one theme would still mean it is catered for by an overlapping theme. For example, G8 noted they wanted to rename their “Energy” category to “Energy, Logistics and Transport” and then remove a token from “Logistics and Transport” given they found the two themes implicitly connected.

4.2.2 Interpretations of ICT's Role. Participants were provided examples of how ICT is applied within the categories (Section 3). Yet, similar to the interpretations of the themes (Section 4.2.1), participants had preconceptions of ICT's role within these themes, which consequently impacted their prioritisation. For example, P3, P5, and P20 all gave explicit examples of ICT for healthcare that led to them regarding this theme as important; P11 also noted how ICT could be used in 'Government, Policy and Law' for e-voting and e-petitioning. Conversely, P3 explained that they allocated a token to "Government, Policy and Law" on the basis that this was in favour of more strongly governing ICT rather than, say, placing an emphasis on "AI judges for example in the legal sphere." This is similar to G9, who contemplated allocating tokens to "Robotics" and "Business and Commerce" on the assumption that both required ethical oversight. P6 reflected that G3 would've probably chosen different priorities if the role of ICT was more defined "in terms of whether you view it as IT, how IT can affect these [categories]or how these [categories]affect IT, or is it a combination."

ICT's role in some themes was difficult for participants to understand (e.g., Natural Sciences: P3, P5, P12, P19–20), and thus the emphasis they placed on this was reduced—as P11 describes: "either I don't have much understanding of or I, I guess from my own experience I don't see much impact of or on, in terms of ICT [...] I've just assigned where I just think there is that potential impact, does that makes sense?" Similarly, the themes led the participants to discuss world problems (e.g., making governments accessible), with P5–6 and P10 reflecting that some problems may not require ICT solutions. For example, P6 described having to remind himself that they were prioritising tokens based on ICT's role in the themes, rather than allocating tokens to a theme itself: "you kind of keep having to take a step back and say in terms of IT prioritisation, cause it's very much, like the instinct was like that needs more funding: government, policy."

4.2.3 Interpretations of the Prioritisation. The participants took different interpretations toward the exercise of allocating tokens to themes. Part of this was due to the tokens being broadly defined as "resources" (e.g., money, environmental resources, workforce labour—Section 3), and for the most part, tokens were seen as money, funding or investment. Only one group (G4) made an environmental interpretation of the tokens and P20 noted they saw the token as an *"abstract concept."* Yet there were different perspectives to how they imagined the themes—and often the world—with, or without, token allocation. For example, P9 and P16 saw "Manufacturing" and "Business and Commerce" as being able to "figure themselves out" (P9) or "look after themselves" (P16) without ICT prioritisation—similar to P5 who reflected: "health, medicine and psychology, people are interested in that right, even without prioritisation." This may be due to the perspective they took to the exercise, as while they drew on their own knowledge as experts and citizens, the participants sometimes took the role of allocation to be acting as a government, public or funding body (P9–10 and P15–17)—viewing the allocation of tokens as separate to the research and development of ICT in industry.

Others saw the lack of tokens as detrimental to the theme or society, e.g., P10 mentioned they were "happy to kill [their] manufacturing and give it to logistics and transport", and P8 found the penultimate prioritisation round to be a form of apocalyptic scenario, "this is basically the end of the world, we only have three resources, so nothing matters, knowledge doesn't matter, education doesn't matter, let's just use 1 resource to develop a great medicine to let all of us die with peace, cause really that's the end." G3 were concerned whether no tokens equated to no resources being allocated to that theme at all anymore. For G10, P20 also jokingly described the elimination of tokens as a life with and without certain aspects: "we've got school, with perfect health, and we really like each other, but we can't watch Netflix [laughs]." P19 (G10) instead assumed that removing tokens would only apply to future research and development and reflected that the exercise made him consider the progression of ICT in this future prioritisation that he would usually take for granted.

4.3 Participants' Considerations for Decision Making

Several factors were thought to be driving the underlying decision-making in the groups, including the need to establish a common foundation, the balancing of risk and reward, and ensuring that decisions were inclusive.

4.3.1 Setting Foundational Understandings. Participants probed the study's definition of ICT (P6), whether allocation approaches should be on personal opinions or societal views (P15 and P18), and whether there were specific time-span or geolocation contexts for the prioritisation (G8). Some participants also thought further detail on the themes would've been helpful (P6, P8, and P19). The wide impact of ICT in other sectors and prioritising tokens for the whole ICT sector made it difficult for the participants to make decisions. P15 and P19 actually both struggled to comprehend whether this was even possible given how society and ICT are structured, e.g., "society, it's you know, it's quite naturally evolving and I think as far as IT prioritisation that is also the case" (P19). P8 also didn't understand the point of *"dictating"* priorities as people have different interests; concern was expressed about authoritarian controls of ICT or dictatorship as P15 put it.

As one potential way forward and as a first step for prioritising tokens across the sector, some of the participants discussed identifying an initial set of values or fundamental issues to address for the greater good (P5–6 and P15), as P6 explains: "at a higher level what you probably want to look at is to prioritise values, I mean before you decide what to invest in, you want to agree on a set of values, you know, what's, is sustainability the priority? Is social equality the priority? Is the economy the priority? I think this is all gonna change depending on the situation and the context." P11 also alluded to this, suggesting the United Nations' SDGs could be utilised as a way to drive priorities.

4.3.2 Ensuring Rewards Outweigh Risks. Some participants were keen to ensure allocated tokens would be used in a way that they deemed positive—noting ICT's costs as well as its benefits (P3, P5–8, and P11). For example, P3 discussed how she struggled with "Robotics" as she has seen autonomous systems be used in great ways, yet is nervous about self-driving cars. P5 had the same concerns for such cars, but considered whether prioritisation would be needed to ensure humans know what to do when an automated machine does something wrong. Moreover, P8 described technology as a "double-edged sword," noting that there is a "considerable amount of risk for ['Government, Policy and Law'-related] systems to do what they're not intended to do"; P7 raised to P8 that risks are present in all themes.

The depletion of tokens was also difficult for most groups, with concerns if too few resources for themes and the neglection of themes in favour of the prioritised—particularly when the non-prioritised themes were still seen as important or valuable. P7 and P12 reflected that they would want to better understand the costs and benefits in terms of how tokens impact a theme (P7) or on society and individuals (P12). However, P7 discussed the difficulty of measuring and comparing these benefits across different application areas of ICT: "benefits [in] the natural sciences world is different to benefits in the education and skills development, so I don't know how you would measure those outcomes as benefits."

4.3.3 Representation of Opinions. Four groups (G1, G3, and G8–9) thought that, to make concrete decisions on where and how ICT is prioritised, it was important to consider potential biases and a variety of opinions. They suggested different groups should be included in decisions, inclusive of various age groups, career stages, disciplines, and professional backgrounds (e.g., politicians, academics, people outside of ICT) and with experience in the themes. For the latter, G1 noted how they both came from an education background and thus were potentially biased toward "Education and Skills Development" and that having people from the different themes may reveal interesting results. P2 even suggested having a representative from every theme at once as "when we talk to each other probably we can make better decisions," and G9 wanted to ensure many disciplines could input to avoid some being neglected at the expense of others (e.g., art).

In G9, P17 emphasised the importance of recognising bias and under-representation when making decisions, "everybody's got a bias, and when you go into a room at a sandpit or whatever, you bring, you can mix things together but there's also people who, the things that aren't represented." However, P5 highlighted how prioritisation can become "muddy" as different people, bodies or corporations are involved given they may have varying conflicts of interests—a view P20 shared in G10, expressing the opinion that priorities need to come from government. While domain knowledge impacted prioritisation (Section 4.1.1) and was seen as helpful (G3 and G8), G8 discussed creating a steering group that included both ICT professionals and 'random' individuals that have an interest in ICT and can provide other perspectives.

5 DISCUSSION

Asking our participants to prioritise ICT innovation was no easy task, yet our exploratory study surfaced interesting tensions and considerations worth further discussion—especially covering who should be prioritising, what and where we should prioritise, and how this could be achieved.

5.1 Who Should Prioritise?

Our participants questioned who should make decisions about ICT innovation priorities moving forward and why they would be best suited to make those decisions. We recruited ICT researchers and technologists as we deemed these groups to have the most relevant expertise to comment on the relative priorities for the ICT sector. However, there was a belief that a variety of different stakeholder opinions should be considered (Section 4.3.3)—perhaps even involving the general public, without specific expertise in ICT—to ensure there is suitable representation of people and opinion. Climate change affects us all globally and ICT is pervasive in many people's lives; so, should not anybody, including non-ICT experts, have a say on ICT prioritisation? It is however difficult to make such important decisions if you have little domain knowledge (as shown with our participants for some of the themes—Section 4.2.2), but it is worth considering how democratic these processes should be. If they should be included, then what information would they require to be able to make sufficiently informed decisions on a subject area they know little, or even nothing, about?

Perhaps one benefit of including non-ICT experts is the removal of work-related biases that our participants raised (Section 4.1.1). The consultation of the general public may allow for a more balanced view that is free from conflicts of interests within the sector. Yet, as identified by our findings, there are a number of influences beyond work and ICT that impacted our participants' decisions such as current events (Section 4.1), and despite having ICT expertise, our participants also sometimes changed the role they took to make priorities (e.g., as an expert, citizen, government or funding body—Section 4.2.3). It is thus clear that all biases must be explicitly accounted for when making decisions, ensuring decision makers declare their conflict of interests and their values or beliefs. Having this understanding of the decision makers themselves should avoid issues such as "chumocracy"[8] and aid transparency of how they interpret prioritisation based on their discipline or world view.

5.2 What and Where Should We Prioritise?

Making decisions for prioritising ICT innovation is no doubt complex. Our participants all interpreted the ICT application areas (Section 4.2.1) and ICT's role in those themes (Section 4.2.2)

[8] A UK term for when people put their friends/ those from similar backgrounds ("chums") into power positions without due process and transparency.

differently—making it difficult to understand really *what* they were prioritising. The prioritisation exercise also made it difficult for participants to remember they were prioritising resources on ICT's use within a theme rather than the theme itself (e.g., resources for ICT in "Government, Policy and Law" rather than resources for Government, Policy and Law generally). Complicating matters further is how interdisciplinary and interwoven with society ICT can be, with the ICT sector seamlessly crossing boundaries to other sectors in the global economy. Our participants thus saw the ICT themes as overlapping and interconnected, creating hurdles for which theme to prioritise.

This raises the following two issues for ICT prioritisation: (1) *Where* do we prioritise? and (2) at *what granularity*? For the former, the ICT sector needs to establish boundaries on what qualifies as ICT and whether priorities should be made by the ICT sector (consuming the ICT sector's carbon budget) or other sectors in the global economy (consuming carbon budgets in those sectors). Put simply: *When is ICT the ICT sectors' problem?* For the latter, our study attempted to understand ICT prioritisation at the level at which it is applied to explore "worthy" vs. "less worthy" uses of ICT [33] and to prioritise ICT by value moving forward, foundational knowledge amongst decision makers is required (Section 4.3.1)—ensuring shared understandings of ICT's application and its impacts. Yet, to remove divergence of interpretation and given broad categories of ICT application will have varying carbon footprints, do we need to make decisions on ICT at a different level of granularity, e.g., available compute in data centres for AI algorithms, or even the number of data centres, networks and user devices that can be used? In prioritising innovation in the ICT sector, we need to set these boundaries and identify the ideal granularity to make reasonable decisions and achievable climate targets.

5.3 How Should We Prioritise?

Our participants' prioritisation approach raised some interesting considerations for whether the sector can be prioritised independently. Some participants struggled to prioritise for ICT as a whole—making the assumption that some ICT application areas would continue to flourish without resource prioritisation. Similarly, participants found it difficult to understand what prioritising diminishing resources for ICT into the future would really mean, since they reasoned ICT is unlikely to be able to continue unmolested separably (with only the future of ICT impacted) when other sectors utilising ICT are reducing their footprints. These highlight considerations for what our carbon budget for ICT innovation covers now and in the future and how we can then prioritise. It also uncovers the tensions of how we prioritise research and development that is made possible by public and private funds, or in academia and industry, so that the ICT sector can innovate responsibly and sustainably without living in (their words) a global dictatorship (raised by two participants).

Our participants were keen to ensure ICT prioritisation enabled significant rewards (Section 4.3.2) and prioritised based on current events (Section 4.1.3) raising questions for (1) how we make decisions based on ICT's risks and rewards, and thus how we establish these risks and rewards now and in the future, and (2) whether prioritisation decisions should be *reactive* to immediate issues determined by current events, or *proactive* pre-empting future issues that could arise.

Taking these all into account, it is clear much further research and evidence gathering is required *with various ICT stakeholders* to answer these questions, and to understand exactly how we can best prioritise ICT across the sector in a way that aligns with the Paris Agreement and is endorsed by ICT stakeholders (e.g., researchers and technologists).

6 IMPLICATIONS

In considering the who, what, when, and how of prioritising ICT innovation under declining carbon emissions, we must address the emerging tensions and considerations in making such decisions, and as a starting point, the challenges revealed by working with our participants. In this section, we outline a new area of research for the sustainability of the ICT sector, and specifically HCI, to help support the ICT sector in uncovering and resolving these challenges—enabling the ICT sector to prioritise its innovation and align its emissions with the Paris Agreement.

6.1 Bringing Together Socio-technical Evidence

There is the need for an evidence base including quantitative and qualitative data to inform decision-making for ICT innovation priorities (Sections 5.2 and 5.3). Developing this evidence does not lie solely with HCI, yet the field is well placed to work across disciplines and thus we see HCI's role as drawing the evidence together. From a carbon perspective, the ICT sector needs to know what it means for ICT innovation to be aligned with the Paris Agreement: what carbon budget the sector has, how much carbon is required for ICT applications (at varying granularities), and how valued assemblages of ICT should make up the sector's available carbon budget. This requires examining *ICT's carbon impact*, doing so comprehensively and repeatedly, with a trusted methodology. The challenge of scoping and creating this evidence base should not be underestimated, but there is undoubtedly going to be continuous uncertainties regarding ICT's carbon impacts and this should not stop the ICT sector from taking action [51]. Thus, we would argue for an incremental approach resulting from active research into this area, rather than pausing urgent prioritisation until such evidence is "complete."

Prior work on the climate impacts of ICT has emphasised the need for carbon accounting that is fully inclusive of emission scopes 1–3, and considers both the ways in which ICT efficiency gains can *rebound* to increase overall externality or might enable the saving of emissions in other sectors (*enablement*) [33]. The rebound effects of ICT are subtle and pervasive [10, 18, 24]: We refer to any increase in overall emissions that result from the application of ICT to a sector both directly and indirectly. By way of example, smart home heating counter-intuitively can increase energy consumption by extending heating hours by pre-heating homes automatically to meet user expectations or by making control of heating simpler and more usable [86]; in addition, e-commerce may offer access to lower cost products, making money available for increased consumption [18]. Conversely, ICT can enable reductions in global emissions in other sectors, e.g., mobile applications that facilitate the use of shared resources such as car pooling, or IoT for "smart roads" that relieve congestion and air pollution [38]. While the tradeoffs and implications of ICT's impacts are complex to assess and hard to generalise, it is important we can collate and contrast ICT's systems-complete rebound and enablement effects to fully appreciate ICT's tradeoffs and possible impacts on global emissions (cf. Reference [85]). Understanding how the ICT sector's emissions forms a part of, or interlinks with, overlapping sectors in the global economy (Section 5.2) will help define whether ICT can have a larger or less rapidly decreasing carbon budget if justifiable by demonstrably creating significant emission reductions in other sectors [33].

As we have explored with our participants, however, there are other concerns that need to be balanced when prioritising ICT innovation that go beyond ICT's purely environmental impacts, such as the "greater good" that ICT can bring (e.g., using AI for HIV prevention or combating wildlife poaching [39]). Such concerns are important to consider to ensure the overall reward of a technology outweighs its risk (Section 5.3). There is likely no single answer; balancing these difficult tradeoffs will be a matter of creating good governance and responsible innovation. The HCI community is arguably well established in exploring the various ethical implications of ICT and impacting society positively [5, 45, 47, 53], such as designing technology responsibly [40], for digital well-being [20, 60], or for social justice [28, 32]. But it is critical that these possible and sometimes speculative promises of ICT are not *always* placed ahead of the environmental concerns, a value that aligns with life-centred (rather than human-centred) design [14].

In resolving this, our study also points to the importance of *"values"* [48, p. 4] in exploring participants' perceived benefits and drawbacks of ICT innovation now and into the future. We need *concrete* evidence on ICT's social implications that enables assessment of its socio-technical tradeoffs. This is a non-trivial task given ICT is so human centric [74], yet one that follows motivations for HCI's Value Sensitive Design [36] in fostering and balancing human values [35] for the *choice* (rather than design) of ICT. Researchers in values in Computing have knowledge surrounding making values visible or quantifiable for decisions [30], and thus we see fruitful collaboration with these groups to ensure we have a truly socio-technical evidence base: one that allows the ICT sector to compare the risks and rewards between ICT's environmental and social impacts (e.g., on equality, trust, social justice, security, privacy, health, well-being etc.).

Following this, the HCI community should consider how ICT stakeholders (e.g., academic institutions, organisations) can respond to socio-technical criterion for the evidence gathering of ICT's tradeoffs, now and in the future. To evidence how these impacts may change, HCI researchers could more deeply engage in speculative design methods [67, 72] in this space to better reflect on ICT's future effects—enabling predictions to be made on whether different ICTs will provide net-risks or net-rewards. With such a socio-technical evidence base, the HCI community can—as activists, educators and professionals—provide this evidence to relevant ICT stakeholders in industry, academia and policy, and enable the sector to make *non-refutable, evidence-led* prioritisation decisions for Paris Agreement alignment.

6.2 Incorporating a Global Context

The ICT sector needs to further unpack *how* it can prioritise innovation across its *entire sector* using available evidence. Our study highlighted the challenges of ICT crossing many boundaries (Section 5.2)—disciplines, organisations, funding sources, countries, values, and so on—making scalable ICT prioritisation inherently difficult. For example, how might different funding sources involving public and private money impact priorities (Section 5.3), since different countries have varying governments and policies for the regulation of public and private sectors, and many ICT companies are multi-nationals? Even beyond ICT, the Paris Agreement that provides governance for different countries to reduce their environmental impact in line with specific targets has not been pledged by all countries worldwide [21]; this makes it hard to believe that the ICT sector will itself be able to achieve what the Paris Agreement has not. However, ICT is seen as vital in the climate crisis [38], and given this, it it is crucial we are able to make evidence-led decisions on the sector's innovation.

Adding to the challenge of prioritising across boundaries, our study participants indicated that ICT priority decisions should be democratic and inclusive of those impacted by the prioritisation. Thus it may be the case that everyone—in and beyond the ICT sector, regardless of their demographic—is allowed to have a say on ICT prioritisation (Section 5.1). If so, then further complexities lie with understanding how different members of society (e.g., academics, ICT industry leaders, general public) can have their opinions considered appropriately, and what mechanisms can be established to enable decision negotiation (e.g., member elections for an "ICT sector governance steering group," building on how governments and funding bodies work today). To do this effectively, everyone should be able to make informed decisions and understand *why* the sector must prioritise, and any conflicts of interests should also be accounted for (Section 5.1).

For our exploratory study, we developed a baseline of research being conducted on major ICT trends in the UK (Section 3); but this is too UK-focused for a global sector and based only on innovation that is publicly funded and thus accessible. To enable data collection and decision-making at a global scale, the ICT sector needs to investigate what processes and procedures would be required to collect a baseline of the ICT innovation currently conducted by various organisations, institutions and individuals worldwide both public and private, and the innovation they expect to conduct in the future.

We still do not have the answers and rightly should not dictate how these globally scalable data gathering and prioritisation processes are set to ensure Paris Agreement alignment. In fact, our study is the first to our knowledge in HCI that directly responds to this climate change goal [79], and yet Thomas et al. [79, p. 6989] note that "The HCI community's interdisciplinary strengths could place many members in a unique position to engage with the digital dimensions and implications of [environmental public policy]." We too see these strengths of HCI to facilitate ICT *governance* for sustainability, and suggest the HCI community can conduct transdisciplinary research to explore these tensions across boundaries, society members and ICT stakeholders. The Paris Agreement will cascade down to all sectors, and the ICT sector needs to be able to govern ICT innovation when it does. As such, we urge the HCI community to collaborate with experts working in the space of "anticipatory governance" [41] as a part of Responsible Research and Innovation [40, 87] to further anticipate the environmental and ethical implications of prioritising ICT amongst ICT stakeholders. Not only would these implications be useful for ICT's role in environmental sustainability, but would also help the sector understand how it may govern ICT for its other negative social impacts [84], e.g., on privacy and bias.

6.3 Transparent Tools for ICT Priority Decision-making

While socio-technical evidence is paramount for the ICT sector to make decisions on ICT innovation priorities (Section 6.1), such data would be useless without the ability to visualise and analyse it in line with global carbon targets such as the Paris Agreement. Pargman et al. [65, p. 293] note that there is a need for better digital tools that visualise flight-related data to "guide any change process and reduce carbon emissions" involved with flying; we argue a similar tool is required for ICT and that the HCI community can help design and develop such a tool [26] for the ICT sector to use (drawing on concepts of "Green Policy Informatics" [16]). Through this, the data on ICT's environmental and societal impacts would be able to be evaluated in one space—allowing the sector to explore how prioritising different ICT innovations of value affect its carbon budget and how that can bring global net-benefits.

We see such tool development as an opportunity to connect ICT stakeholders to their actions and consequences, shaping environmental movement in the sector [29]. Aligning ICT with the Paris Agreement would involve bringing together the stakeholders required for making ICT priority decisions, making decisions visible, and providing a historical trail of socio-technical evidence and decisions for future scrutiny. This would ensure that ICT sector decisions are fully *transparent*, a quality paramount to ensure the sector can reason about all priorities (regardless of if they are reactive or proactive—Section 5.3) and alleviate the challenges regarding ICT's global context (Section 6.2).

Taking this further, such tools could highlight the values, backgrounds, and other influences or biases that decision makers themselves bring to prioritising ICT innovation (Section 5.1). For example, if a specific ICT priority aligns with a decision maker's work (potentially creating more funding for their research or easier ways for them to profit), then a decision-making tool should be able to recognise this strong correlation and openly flag this to the publicly available data. There is also the question whether priorities should be given less weight for decision makers that have "conflicted" priorities and how conflicts between decision makers can be identified and logged (avoiding 'chumocracy'—Section 5.1).

Understanding how such considerations can be integrated into tools for decision-making to support ICT prioritisation is no mean feat, especially given the precursor challenges of socio-technical evidence and scalability. Yet, developing such tools is a clear design interaction problem that HCI experts can, and should, explore to support. Further adding to this challenge is for HCI research to ensure decision-making tools are fair and transparent about their data, algorithms and analysis. For this, future work should build on lessons learned in HCI from creating decision tools (e.g., used for health [78] or the public sector [82]) to promote rigour and trust.

7 CONCLUSION

As SHCI researchers, we recognise achieving positive impact on ICT's environmental sustainability from the vantage point of HCI is challenging. Not only do we suggest designs that go against traditional HCI narratives, but we also critique our own work for having a too narrow focus (cf. Reference [17]) and not creating enough impact [49]. From our prioritisation exercise and discussions with ICT stakeholders, we propose a new area of research for HCI to lead on for responsible and sustainable ICT, comprising of urgently compiling a socio-technical evidence base for the ICT sector to make priority decisions on, understanding how the ICT sector can make priority decisions and societal tradeoffs in a global context, *and* designing transparent digital tools that aid the ICT sector in making priority decisions on its innovation in the increasingly limited time there is to meet global climate goals. Through this, we envision the HCI community can utilise their socio-technical expertise and expand its focus with experts in responsible computing to help the ICT sector traverse a new pathway for sustainability, differing vastly from the "ICT status quo" of continuous innovation and growth.

While the stakes are high, we wish to remind readers that the HCI community need not be alone in this: our implications call for transdisciplinary research that encompasses ICT stakeholder involvement, and we simply propose the HCI community is well placed to glue relevant research and associates together. By utilising the socio-technical expertise that HCI embodies, the HCI and responsible computing communities can support the ICT sector in priority decision-making (as highlighted in our implications for next steps in this domain), as well as build upon what we have started through our study to expose further tensions of ICT innovation prioritisation amongst different stakeholders and under varied criteria. As activists, educators and professionals, such communities can then utilise this work to influence others in the ICT sector—particularly industry and academic leaders, as well as policymakers, who can hold the sector accountable for ICT's environmental impacts.

Given the ICT sector is broad in the innovation it provides, we suggest this avenue for responsible and sustainable ICT should initially focus on supporting the ICT sector in prioritising a subset of ICT innovation under constraints: Freitag et al. [33] found that the growth and environmental impacts of AI, IoT, and Blockchain (e.g., for AI training [11], for IoT's vast expected growth [75], Bitcoin as an application of Blockchain [25]) could have profound effects on ICT's future emissions. This work can leverage and extend research examining the ethical issues in regards to these trends in ICT, such as guidelines of AI [46], challenges for IoT [3] and issues of Blockchain [77]. Focusing on these trends should expose the key tensions for prioritising innovation in the ICT sector as a whole and support the ICT sector to make effective priorities that enable significant inroads in reducing ICT's carbon footprint to align with the Paris Agreement.

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