

Further Connecting Sustainable Interaction Design with Sustainable Digital Infrastructure Design

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ABSTRACT

This paper advances the connections between sustainable interaction design (SID) also known as sustainable HCI (SHCI) and sustainable digital infrastructure design (SDID), building on prior work in the HCI archive. We describe trends in sustainable interaction design. We ask four fundamental questions as a synthesis of SID and SDID, namely how can we reduce environmental harm now, alter practices to reduce environmental harm in the future, alter practices to promote a healthier society, and create new technology and practices to face future challenges? We relate these questions to frameworks of analysis in SID and SDID, as well as to transdisciplinary design. To illustrate the importance of these questions, we present and relate three conceptual design scenario discussions that may be characterized in human-centered terms of analysis as (a) finding balance, (b) resistance to technologies that push more consumption, and (c) observing a day of rest.

CCS CONCEPTS

• **Human-centered computing** → HCI theory, concepts and models • **Human-centered computing** → Interaction design theory, concepts and paradigms

KEYWORDS

Sustainability; Interaction Design; Digital Infrastructure; HCI; Human-Centered Design; Cloud Services; Specific Applications; Transdisciplinary Design; Sustainable Design Frameworks; Design Processes; Design Thinking; Day of Rest; Resolution; Disconnecting, Finding Balance.

INTRODUCTION

This paper concerns making connections between sustainable interaction design (SID), also known as Sustainable HCI (SHCI), and sustainable digital infrastructure design (SDID). The paper advances, builds on, and seeks to help fill in some details of two prior papers in particular, namely “*Understanding and Mitigating the Effects of Device and Cloud Service Design Decisions on the*

Environmental Footprint of Digital Infrastructure” [39] and “*Sustainable interaction design: invention & disposal, renewal & reuse*” [7]. This paper takes a design criticism perspective, taking up three *conceptual design scenarios* about three privileged themes, namely (a) *finding balance*—Figure 1, (b) *resistance to technologies that push more consumption*—Figure 2, and (c) *observing a day of rest*—Figure 3. The meanings of these aesthetically composed figures are described in the conceptual design scenario sections of this paper. Some figures in this paper have appeared elsewhere as noted. All are used with permission. Abbreviations, as there are more than a few in this text, are explained in Table 1 (Page 3).

Method & Organization

First, we describe trends in SID/HCI. Next, inspired by notions of *what we must do* in the perspective of Design’s imperative for preserving and improving quality of life, we ask four fundamental *overarching concept generative questions* (OCGQ) with short titles in the imperative voice, namely (1) **Understand & Reduce**: How can we understand and reduce the negative environmental impacts of existing practices supported by the technologies we design, while taking human wants and needs into account? (2) **Uncover Assumptions**: What implicit values and assumptions are embodied by the practices our technology encourages which result in environmental impacts? Can we make these explicit, provide alternative perspectives, and encourage alternative practices in designers and people? (3) **Match Practices to Wellbeing**: Do the practices encouraged by the technology support or work against the wellbeing of the individual and society? What can be done to mitigate this or promote alternative practices? (4) **Consider Resilience & Preparedness**: Are the practices encouraged by the technology resilient to future environmental and societal challenges we may face? Do they encourage preparedness?

Next, we describe each of these questions in terms of how they act to overarch selected concepts from SID and SDID. For example, *understanding the negative environmental impacts of existing practices* from the first fundamental overarching question above entails understanding the concept in SID concept of *promoting renewal and reuse* and the SDID concept of the infrastructural effect of *digital waste*. We present a full list of these concepts as an Appendix in the supplemental materials—we call it an inventory of analytic and concept-generative principles and frames in SID/SDID. The basis for selecting which concepts are presented in this paper is how they relate to the four questions above and how they play a role in the conceptual

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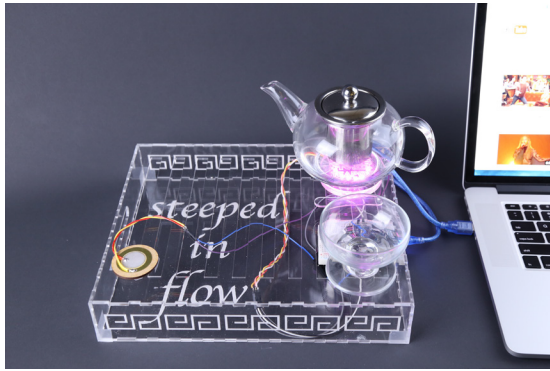


Figure 1. Balance (image © P. Ho)



Figure 2. Resolution (image © E. Bleviss)

design scenarios that follow. To be clear, these overarching questions should not be taken as a substitute for asking other detailed questions where relevant to a particular design. Rather, these four questions are a framework for motivating understanding among the large set of considerations which form part of SID/SHCI and SDID, and they are a framework for guiding the application of specific such considerations in specific design cases.

In the second half of the paper, we develop the three aforementioned conceptual design scenarios. We show how each conceptual design scenario sheds light on one or more of the overarching questions. We relate each conceptual design scenario to specific concepts from SID/SHCI and SDID, chosen from the inventory in the supplemental materials. The complete list of concepts can also be found directly in the two sources [7,39] we identified at the outset, and that is the recommended course for the reader who would like a complete account.

Each of the conceptual design scenarios ends with an analysis using a frame that owes to an interpretation of transdisciplinary design theory, as described in [31]. The transdisciplinary design frame (TDF) is a reflective device that targets a values-rich account of a design, namely (a) *what we must do*, (b) *what we want to do*, (c) *what we can do*, and (d) *what we can know*. The interpretation of [31] that leads to this frame is described completely in a forthcoming paper.

The three conceptual design scenarios are free form. That is a familiar technique in Design and a feature of this method. Each



Figure 3. Rest (image © E. Bleviss)

theme—*finding balance*, *resisting technologies that push more consumption*, and *observing a day of rest*—begins as broadly divergent, freely imaginative discussion. Such divergence is essential to creative design. The overarching questions and the concepts from the inventory help contain the discussion. Finally, the transdisciplinary design frame helps to shape a convergent conceptual view at the conclusion of each conceptual design scenario.

The free form nature of the conceptual design scenario discussions may be familiar to and comfortable for readers with Design studio background, and possibly discomforting to readers from more teleological disciplines who sometimes expect that Design concerns problem solving in the context of detailed problem setting by others. This paper is a collaboration between computer scientists (cf. Simon's *Sciences of the Artificial* [46]) and designers (cf. Margolin's *Politics of the Artificial* [29]). The overarching questions, inventory of concepts, and transdisciplinary frame are one form of first-order structuring of this free form ideation. We argue that this is a contribution, albeit one that may take those from various perspectives on the *HCI as science* to *HCI as politics* spectrum into less familiar yet fertile territory for further discussion and ideation in the service of SID/SHCI and SDID.

TRENDS IN SID/SHCI

In the general area of sustainable interaction design, we can focus on three issues that are foundational to understanding how thinking about sustainability has evolved and refined over the last decade. We'll title these issues (1) invention and disposal, (2)

political economy, and (3) levels of design focus. These issues amount to analytic trends, some well-known and some less well known within HCI. Before we further connect SID and SDID beyond [39], we first describe these three issues that we will later use in part as an additional instrument beyond [7] and [39] for making the connection.

Invention and Disposal: New and Old

One of the most familiar issues in SID is the issue of how much environmental cost is associated with the use of designed digital devices, compared with how much is associated with the exchange of such devices. This is an equation about net effects. That is, if manufacturing, distributing, and using something new causes less environmental damage than using, disposing, recycling, or remanufacturing the old thing that the new thing displaces, it is likely better to use the new thing. On the other hand, if using something new causes more damage, it likely does not make sense to displace the old thing. However, this is not an easy equation to calculate. There are a great many variables to consider on a case by case basis. For example, there is a possibility that a new design or technology provides increased capacity that induces more use, more resource consumption, and more environmental cost. Understanding the links between invention and disposal is an established and ongoing concern of SID/SHCI that underlies much of what is framed in [39]. Notwithstanding, there are other trending issues to also consider.

Political Economy: Shifting Responsibility

Another, more recently foregrounded issue is the one of who and/or what is responsible for increasing environmental costs associated with increased development and use of digital devices and services. This is an equation about political economy. Roedl [41], following from Harvey [20], notes that much of commerce is motivated by the differences between use and exchange. He argues that businesses tend to derive the most profit from exchange of goods or services, rather than use. Thus, it is generally in the interests of businesses to sell new things to people, even if the things people already have still have a useful service life. In the case of digital infrastructure—that is, the energy implicated in the production and consumption of digital services—the *new thing* is typically increased bandwidth and cloud storage capacity, which in turn leads to increased device and energy use consumption. That is, the exchange value is in the devices and services germane to increased bandwidth and capacity. Furthermore, the increasing power of the infrastructure allows people to rapidly upgrade and expand the functionality of their devices—through new apps and web services—which can result in *person-driven obsolescence* as the device is no longer fit to service the demands placed on it by the content formats that people newly want to access.

Moreover, the marketing of *newness* and *desire* transfers responsibility for this consumption to the people who buy things—including increased bandwidth and cloud storage, rather than to the businesses that seek to alter individual acquisition and disposal behaviors. People come to believe that they are the ones who are responsible for governing their consumption, rather than the businesses that seek to induce greater consumption. This equation is also not simple. It seems there

Abbreviation	Explanation
OCGQ	Overarching Concept Generative Questions
SDID	Sustainable Digital Infrastructure Design
SDID-Principles	Reflective principles of SDID
SID/SHCI	Sustainable Interaction Design/HCI
SID-Principles	Reflective principles of SID
RoME	Rubric of Material Effects (SID)
RoIE	Rubric of Infrastructure Effects (SDID)
RoIE-Cornucopia	Rubric of mistaken beliefs in endless supply (SDID)
RoIE-Infrastructure	Rubric of infrastructure preserving decisions (SDID)
RoIE-Limits	Rubric of infrastructure decisions within resource limits (SDID)
RoIE-Collapse	Rubric of infrastructure decisions in the face of collapse (SDID)
RoIE-Responsible	Rubric of socially responsible infrastructure decisions (SDID)
TDF	Transdisciplinary Design Frame

Table 1. Table of Abbreviations

must be ways for businesses to partner with people to reduce consumption, and still maintain a viable economy—that is, create a resource sustainable economy. However, discovering such ways is an elusive matter. There are some notable and noble efforts in this direction. For example, the Fairphone (as reported and evaluated in Joshi & Cerratto-Pargman [25]) targets a sustainable model of modular, upgradeable product design. Bonanni [9,10] has translated his work on supply chain transparency as a matter of sustainability into a viable enterprise (www.sourcemap.org). The notion of political economy as a concern of HCI is taken up in Ekbja & Nardi [14,15], wherein associated writings are reported.

In general, services that claim to be *new and improved* are those that find ways to exploit increased bandwidth to provide a perception of *richer experience*. However, there are some exceptions—for example the eBook and reader, which offers a simpler and slower access to the internet tailored to reading, and derives its value from the quality of the content rather than an enriched experience of format.

Further to these notions of political economy, it would be not uncommon to consider that digital energy infrastructure is more of a utility, and is therefore economically a matter of use, rather or more than a matter of exchange. That is reasonable. Notwithstanding, rapid advances in digital bandwidth induce rapid changes in the way that people use digital energy infrastructure. This creates the same kind of or even more rapid obsolescence of associated physical devices and environmental costs of consumption than traditional product categories have and continue to induce.

Levels of Design Focus: Individuals & Behaviors, Community & Practices, Governance & Policy

Another recently foregrounded issue is the one of at which level design and designers can and should operate. Much—not all—of what has appeared in the HCI literature about sustainable design focuses on individual behavioral change. Some have argued that

HCI must move beyond the individual in order to achieve traction with respect to sustainability (e.g. Bates et al. [3], Brynjarsdóttir et al. [11], Hazas et al. [21], Knowles et al. [26,27], Silberman et al. [44]). Some have called for greater focus on designing for sustainable practices at the level of community. Some have called for greater focus on design’s confluence with policy at the level of governance. These levels of focus are discussed in Tomlinson et al. [49], and others (e.g. Pargman [37]). Norman & Stappers [33] have described the need for greater emphasis on policy level design in the new design journal, *She Ji*, as has Whitney [50]. Ostrom [35] described polycentric forms of governance as a proposal for how to achieve sustainable policy, as part of her Nobel Prize winning work, and that work has been referenced in the SID/SHCI literature (e.g. Silberman et al. [44]). Nathan & Meyers [30] recently argue for expanding the breadth of perspectives on sustainability.

Understanding these levels of focus helps augment perspectives on SDID. For example, note that cloud service providers and others oftentimes work at the levels of community and practices in addition to the level of individuals and behaviors to promote increased consumption. A cloud storage company may offer individuals free extra storage for recruiting friends and colleagues to the service. People use the service so extended to share documents and photos and other digital media with one another and become increasingly reliant on the service in their practices and communities. As a result, they become willing to pay for the premium service which once they did not need.

Transdisciplinary Design Theory & Frame

Another trending theory germane to the sustainability discourse is the notion of transdisciplinary design. This has been discussed in HCI (e.g. Blevis [5], Blevis & Stolterman [6], Rogers [42]), wherein it is attributed to Max-Neef [31] and Nicolescu [32]. The theory is intricate, but for our purposes here we can state that to be transdisciplinary—a portmanteau of *transcend* and *disciplinary*—requires in a minimal sense that an interdisciplinary or multi-disciplinary project is not just a mixture of any disciplines at all, but rather a mixture of specific disciplines that distribute in their foci over four foundational questions. Borrowing terminology from [5] that is directly inspired by [31], these questions form a *transdisciplinary design frame* (TDF):

- (1) **Must do:** How does what we propose to do contribute to understanding or doing what we *must* do, as a matter of values and ethics?
- (2) **Want to do:** How does what we propose to do contribute to understanding or doing what we want to do in support of what we must do?
- (3) **Can do:** Can we do what we must do and want to do?
- (4) **Can know:** What can we know about what we propose to do?

CONNECTING SUSTAINABLE INTERACTION DESIGN WITH SUSTAINABLE DIGITAL INFRASTRUCTURE DESIGN

In this paper, we engage these and other issues specifically with respect to digital infrastructure—that is the energy used to support digital devices and services.

Overarching Concept Generative Questions (OCGQ) Relating SID to SDID	Sustainable Interaction Design (SID) Principles	Sustainable Digital Infrastructure Design (SDID) Principles
<i>Understand & reduce</i>	Linking invention and disposal	Linking infrastructural expansion and obsolescence
<i>Understand & reduce</i>	Promoting renewal and reuse	Promoting infrastructural use-efficiency and sharing
<i>Match practices to wellbeing,</i>	Promoting quality and equality	Promoting reliable infrastructure from sustainable sources, Promoting equitable distribution of bandwidth
<i>Uncover assumptions, Match practices to wellbeing</i>	De-coupling ownership and identity	Promoting online/offline life balance
<i>Uncover assumptions, Consider resilience & preparedness</i>	Using natural models and reflection	Eliminating wasteful use of infrastructure, Making infrastructure use transparent, Computing within limits

Table 2. Correspondences of Overarching Concept Generative Questions (OCGQ) with SID and SDID Principles

Preist et al. [39] takes up these issues of energy use and design choices relating to the use of digital media. That paper proposes four frameworks that operate at four different levels with the intention of informing design decisions with respect to digital infrastructure. This paper advances that work by making explicit the connections between these frameworks and their partial inspiration in prior work [7], wherein Blevis proposes five design principles and a rubric of material effects to characterize notions of sustainability in interaction design. As these two papers are the anchors for the present discussion, we refer hereafter to [39] as “*the SDID paper*,” wherein “SDID” stands for as we have noted “Sustainable Digital Infrastructure Design,” and to [7] as “*the SID paper*,” wherein “SID” stands for as we have noted “Sustainable Interaction Design.”

Reflective and Concept-Generative Sustainable Design Principles

The design questions given by SDID and SID provide an inventory of questions that can be used as a ‘critical lens’ when analyzing designs. In applying transdisciplinary design theory we now reframe these questions to arrive at four overarching questions that are not only *reflective*, but also *concept-generative*. Each of these questions is linked to a different aspect of *what we must do*.

In applying transdisciplinary design theory to sustainable design we are led from the present to the future by asking how we can reduce environmental harm now, alter practices to reduce environmental harm in the future, alter practices to promote a healthier society, and create new technology and practices to face future challenges.

Correspondingly, the following four categories of design questions represent the full set of questions in the frameworks in the SID and SDID papers and in the Appendix to this paper from four orthogonal viewpoints. Assuming these different perspectives through the critical lens of the individual questions is a principled and methodological approach to the complexity that is SID.

Understand and Reduce: How can we understand and reduce the negative environmental impacts of existing practices supported by the technologies we design, while taking human wants and needs into account?

The related concept-generative design principles from the SID paper are the principle of promoting renewal and reuse, and the material effect of recycling. From the SDID paper, we have the infrastructure effect of digital waste. These appear in the Appendix as SID-2 (Promoting renewal and reuse), RoME-3 (Recycling), and RoIE-6 (Digital Waste).

Uncover Assumptions: What implicit values and assumptions are embodied by the practices our technology encourages which result in environmental impacts? Can we make these explicit, provide alternative perspectives, and encourage alternative practices in designers and people?

The related concept-generative design principles from the SID paper are the principle of decoupling ownership and identity, the material effect of sharing for maximal use, and the material effect of achieving longevity of use. From the SDID paper, we have exposing the untenable nature of the cornucopian perspective—the perspective that digital infrastructure is limitless, and the infrastructure effect of making infrastructural use explicit—that is visible. These appear in the Appendix as RoIE-Cornucopia (Making the inadequacies of this framing explicit), SID-4 (Ownership and identity), RoME-7+8 (Sharing + Longevity), and RoIE-10 (Making infrastructural use explicit).

Match Practices to Wellbeing: Do the practices encouraged by the technology support or work against the wellbeing of the individual and society? What can be done to mitigate this or promote alternative practices?

The related concept-generative design principles from the SID paper are the principle of promoting quality and equality (of experience), and the material effect of providing wholesome alternative to use. From the SDID paper, we have the principle of promoting online/offline balance, the principle of computing within limits, and the infrastructure effect of forming a healthy relationship with technology rather than a dependency on it. These appear in the Appendix as SID-3 (Promoting quality and equality), SDID-5 (Promoting online/offline balance), SDID-8 (Computing within limits), RoME-9 (wholesome alternatives),

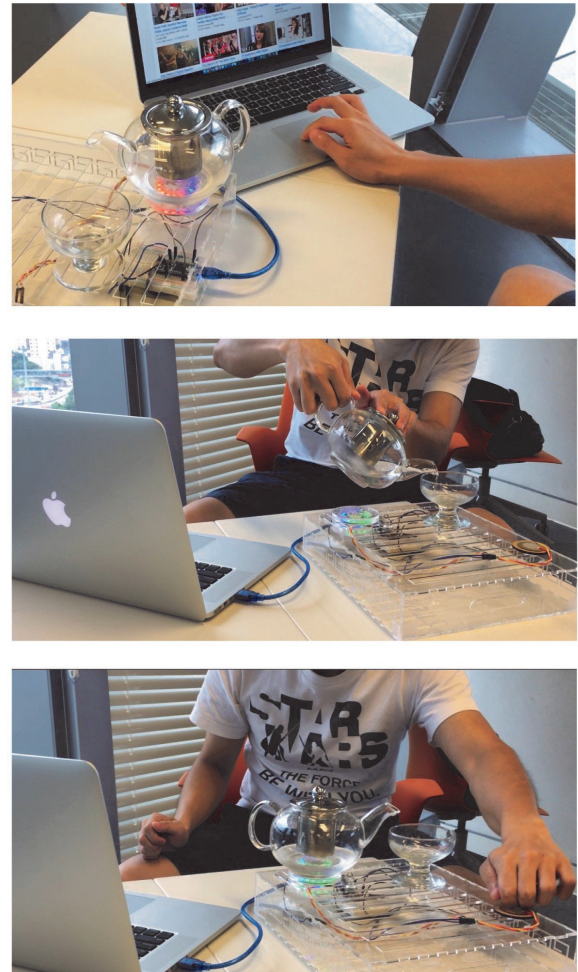


Figure 4: Flow (image © P. Ho)

RoIE-Responsible-1 (Healthy relationship vs. dependency) in the Appendix.

Consider Resilience & Preparedness: Are the practices encouraged by the technology resilient to future environmental and societal challenges we may face? Do they encourage preparedness?

The related concept-generative design principle from the SID paper is the principle of using natural models and reflection. From the SDID paper we have the principle of computing within limits and the infrastructure effect of considering limits and the possibilities for collapse. These appear in the Appendix as SID-5 (Using natural models of reflection), SDID-8 (Computing within limits), and RoIE-Limits & Collapse would be relevant design principles to help guide more SID and SDID practices.

Each question in the inventory of principles, RoME and RoIE, when applied to a design case, can be viewed as a different ‘lens’ through which to view it. As such, it may yield new insights applicable within and beyond the case (or, for many items, may yield nothing new).

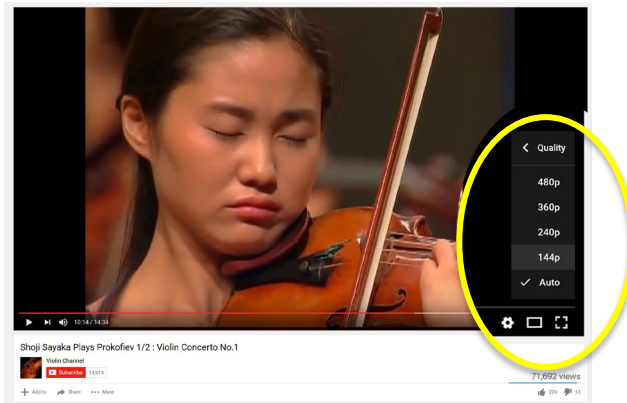


Figure 5. Resolution



Figure 6. Resolution (image © E. Blevis)

These overarching questions, and the structures the frameworks provide, help guide this process and allow ‘pruning’ of sections identified as less relevant for a given case. Note that the overarching questions should not be taken as a substitute for asking the detailed questions where relevant to a particular design - rather a framework for motivating and understanding the large set of considerations which form part of SID/SHCI and SDID, and guiding their application in specific design cases.

The mappings between these questions and the highest-level principles of the SID and SDID papers appears in Table 2. For additional details of the frameworks of these papers, refer to the texts above and the Appendix in the supplemental materials, or directly to the original papers.

Three Conceptual Design Scenario Discussions

We now apply these analytic and concept-generative tools to specific conceptual design scenarios, not only to test the strengths of the framework, but also to hopefully generate some interesting concepts in the service of a sustainable future with respect to infrastructure and other aspects of interaction design. These scenarios complement the cases in the SID paper. In that tradition, this paper presents three exemplar conceptual design scenario discussions purposed to advance an understanding of how SDID and SID may be further connected. Two of these discussions focus on responding in sustainable ways to the unsustainability of existing interactions, and one focuses on a

design prototype targeted at inducing more sustainable and healthy relationships with digital interactive technologies.

Inspired by a technique introduced in the SID paper, the design case discussions refer back to specific elements of specific frames in the inventory. In the SDID paper, the framework elements are first identified and then illustrated with examples. This paper inverts that order and starts with three examples, and then applies the frameworks by appealing to the four overarching questions. A parallel methodological framing inversion exists in the SID/SHCI literature in the relationship of Remy et al. [40] to Odom et al. [34] with respect to frameworks of attachment.

Of these examples, (a) one concerns a design prototype—a digitally connected tea service targeted at creating “flow” (b) one concerns a present SDID practice—choices of resolution, and (c) one concerns a present everyday energy infrastructure policy.

The three examples form a logical tableau for a very human-centered interpretation of how SID and SDID may be connected. That is, the three examples stand for three very foundational human needs and goals with respect to technologies, namely and in parallel with the preceding paragraph (a) finding balance, (b) resistance to pushing more, and (c) observing a day of rest.

These design discussions are also intended to be somewhat progressively provocative. The first is less abstract than the second and the second than the third. The more abstract, the longer the discussion.

Conceptual Design Scenario: Finding Balance

Figures 1 and 4 show an interaction design project inspired by notions of work and life balance. This is a completed project. The thinking that went into this project was prompted in part by the SID and SDID papers.

The project is inspired by various design research concepts, including disconnecting, flow (after Mihály Csíkszentmihályi [12]), and FOMO—*fear of missing out, a phenomenon related to constant connectivity to social media and digital devices*. The project is a digitally connected tea service, named “Steeped in Flow.” The designer, Priscilla Ho, states that the project is connected as a genre to disconnecting, maker culture, well-being, and performative objects. Ho [22] provides the following description:

“Apropos of the concept of flow, we may be happier if we spend less time online and more time face-to-face with the people who matter most to us. This interactive tea set allows people to set limits on their online activities. The embedded lights are triggered when these limits are exceeded. The Chinese kowtow gesture is required to reset the tea set lights, a nod to how drinking tea is generally a social activity.”

This project is the easiest to understand in terms of interaction design of the three conceptual design scenarios—that is why it is presented first. Because it is so clearly a tangible, working interaction design project, it helps round out the scenarios with an emphasis on personal and social responsibility to manage time and resources effectively. The most curious twist about it is that it requires the use of more energy infrastructure to induce an overall reduction of reliance on digital infrastructure.

At first glance, the project appears to be targeted at individual behavioral change. It is. However, more than that, it is also targeted at creating work-life balance especially in the presence of an ubiquitous social media by requiring individuals to pause from the online social world to engage in a physical activity associated with the face to face world—*taking* tea. While this version of the project is designed for the use of one person, it is easy to imagine a version which prompts and invites others to be mindful about their daily interactions and pause from their online lives to participate in a social or community practice of *off-lining*, for example, by taking a break or tea time.

Apropos of this conceptual design, the most relevant imperative of the OCGQ is [match practices to wellbeing](#). It also relates to the imperative of [understand and reduce](#). In terms of the Appendix elements, we have SDID-Principle-5 (Promoting online/offline life balance), RoME-9 (Finding wholesome alternatives to use), and RoIE-Responsible-1 (Does the service encourage a healthy relationship with digital technology, and avoid promoting inappropriate dependency on the digital infrastructure?)

Appealing to the TDF, we may understand this project in the following terms: (1) What we **must do** is find balance between our online and offline lives, not only as a means of sustainable use of digital infrastructure as energy, but also as a matter of personal health and well-being; (2) What we **want to do** is resist addictions to online social media and other forms, substituting wholesome alternatives that induce face to face interactions; (3) What we **can do** is monitor use, trigger signals that reflect a person's behavior, for example over-usage and reliance on social media, and replace possibly unhealthy preoccupations online with offline, physical world activities that may encourage face to face, authentic and genuine interactions; (4) What we **can know** is things that can be monitored, for example, how much time is spent scrolling on particularly addictive sites, such as social media and video streaming sites, and possibly measure how much time spent online is too much time away to maintain a healthy, sustainable society.

Conceptual Design Scenario: Resisting Technologies that Push More Consumption

Figure 5 shows how resolution quality control selection in YouTube video streaming presently exists.

In terms of understanding the connection between SDID and SID, the practice that is illustrated of defaulting to the highest resolution afforded by both the bandwidth and the source is low hanging fruit for criticism. The SDID paper states with respect to SDID-Infrastructure (Does the design encourage or discourage digital waste?):

“A common practice, particularly but not exclusively among teenagers, is the streaming of (free) YouTube videos to provide music, without watching the visuals [28]. This anecdotally widespread practice is likely to be responsible for substantial energy waste, both in Google data centres and in the network. Technically, it would not be difficult to remotely detect such behaviour (e.g. when the page visibility API determines the YouTube tab/window is in the background, or when a user queues a long music playlist.) A ‘video on/off’ option could be

provided to override this detection where it makes an error. However, it may be the case that legal (copyright) issues mean this waste cannot currently be resolved in such a way.” [39]:1330.

The SDID paper gives many additional examples and suggestions about strategies to govern resolution choices, either by viewer selection, browser automation, or service *nudges*, or other means. In that paper, the suggested approaches arrive in three categories, namely:

“(i) design a service to encourage users to choose less intensive options within it; (ii) design a service to encourage users to use it, rather than other more intensive services; (iii) design a service to reduce or avoid usage of infrastructure at peak times.” [39]:1329.

What can be added to this discussion? Actually, questions of resolution, quality, and fidelity are very intricate looked at from the perspective of how they impact meanings and how they are implicated in actual needs apart from the purely commercial manufacture of desire.

The performance in the example of Figure 5 happens to be one by the great violinist Sayaka Shoji of Prokofiev's First Violin Concerto. *Maestro* Shoji is particularly acknowledged for her interpretations of this concerto. She is also particularly admired for her delightful facial expressions that are inextricably connected to her interpretations. Sayaka Shoji's facial expressions matter to the meaning of the performance. A listener who listens to this genre of music may sometimes listen to the streaming audio of the performance alone, sometimes video and audio together, and sometimes nothing else will do but to attend the live performance as the highest resolution experience, in the event the opportunity luckily presents itself. One point is that authentic resolution needs depend a lot on human contexts and the same individual may have different needs with respect to the same music at different times. Another point is that it is not easy to know in advance what kind of resolution may be needed when media is produced, and what kind of resolution is minimal to achieve a baseline quality of experience in a particular context.

One could argue that we are making too much out of the difficulties these subtleties present. After all, the three approaches we have quoted from the SDID paper above can only help alleviate unsustainable demand for digital infrastructure as part of the multi-faceted approaches named in that paper and recorded here as part of our inventory of frameworks. Notwithstanding, we also raise the issue of quality, resolution, context, and conveyance (i.e. e.g. YouTube vs concert hall) as drivers of a very complex design space with respect to sustainable digital infrastructure design.

Resisting technologies that push more consumption is not easy. With greater resolution comes increased demand for digital infrastructure, and the ability of product-oriented enterprise to create the perceived need for new devices that can convey these resolutions. Democratizing the experience of an actual concert hall by means of digital conveyances has the potential to greatly elevate humanity, and the potential for an exponential increase in digital infrastructure and the commerce behind it.

Perhaps a way to *square the circle* is to note the difference between *needs* and *wants*, and to further note that a high-quality experience may become an expectation rather than a treat. To truly savor and appreciate quality, it is best not to become habituated to it. One could imagine *rationing* one's allocation of high bandwidth video, and allowing the user to decide which experiences are worth savoring with wholehearted attention, and which are more every day. This appeals to the OCGQ imperative, [match practices to wellbeing](#).

The SDID paper does consider the advent of 8K video (see [51]). More than modest gains in *right-sized* resolution for some contexts may be truly less than modest if the adoption of 8K video becomes prevalent. On the other hand, the proposition of 8K devices and content could possibly be the breaking point that prompts consumers to consider what the right-size is. In the words of William Blake, “*You never know what enough is unless you know what is more than enough*” [4].

With respect to up-sizing, advances in bandwidth and resolution create a demand for new devices. Very oftentimes these devices may be heavier or larger, or less modular in order to accommodate these new capabilities.

Occasionally, down-sizing is also a trend. Consumers sometimes look for lighter devices, while accepting fewer capabilities. Sometimes, lighter devices with the same capabilities as older, heavier ones become available. Screens become bigger. Screens become smaller. Screens become bigger again. The right-size eludes, because there is no one right-size for every context. This property allows product-oriented companies to create the desire among consumers to always have something that is different than what they presently have.

Here are two possibilities that we hope add to the SDID paper as a matter of understanding *right-sizing*, namely (1) arm people with better understandings of resolution as a design tradeoff between information quantity and not just energy, but also weight, portability, sensitivity (e.g. light), and cycles of product obsolescence, and (2) promote the aesthetics of resolution as a matter of style, rather than a quality to avoid cornucopian notions of more is more—that is, RoIE-Cornucopia-5 (People demand high quality). This appeals to the OCGQ imperative [understand & reduce](#).

Figure 2 is taken with a professional 12 MP (megapixel) camera. Figure 6 shows a detail. From Figure 6, we can see that there is more than enough information for the reproduction here. The camera is available in 3 models, with resolutions of 12 MP, 24 MP, and 42 MP. The 24 MP model is the consumer model and the least expensive (in pricing) by a half. The highest resolution camera is sold mainly to professionals who want maximum resolution. The lower resolution camera is sold mainly to professionals who want maximum light sensitivity. Higher light sensitivity implies faster shutter speeds which is really the concept of time. Higher resolution implies larger images which is really the concept of space. Readers familiar with the computing sciences will appreciate that in computational terms, time and space may be traded off one for another.

Our example above illustrates that resolution is traded off against many other factors and that is something that is not well understood by average consumers. Higher is not always better, even though *megapixels* is the metric with which most consumers are familiar. Moreover, marketers may be the source of this misinformation in order to drive consumption of more products. Arming people with an understanding of resolution may help. This understanding could come in the form of clear product labeling, motivated by (1) well-intentioned and competitive enterprise response to collective consumer demand as a matter of practices, or by (2) legislative policy making similar or hopefully even more informative labeling practices required of digital devices in the same way that labels are required of certain other industries such as food, pharmaceuticals, and so forth. These labels could identify which sorts of activities require which sorts of resolutions, and make explicit the relationship between resolution and actual quality, energy use, and so forth. This appeals to the OCGQ imperative to [uncover assumptions](#).

The second possibility—that is, promote the aesthetics of resolution as a matter of style, rather than a quality to avoid cornucopian notions of more is more—is subtle. Promoting the highest quality resolution is not only a matter of technical features, but also a matter of creating desire. In fact, taking a fashion-oriented understanding of digital enterprise (e.g. Pan et al. [36]) could promote resolution as a quality, like color or texture. By *promote*, we mean that the way in which resolutions are used induces the way they are received and desired. Just as you would not make your entire wardrobe from silk even if you could afford it, you probably do not always want the highest resolution as a matter of style and taste—think of deliberately grainy photographs, jeans that are purchased with holes, the *Meitu* makeup app, and so forth. Having the capability to do something does not mean you need to use it all the time, nor is it even desirable. This also appeals to the OCGQ imperative [match practices to wellbeing](#).

Appealing to the TDF, we may understand this discussion's imperatives in the following ways: (1) What we **must do** is waste less by appealing to the imperatives of [understand & reduce](#) and [uncover assumptions](#), and create the desire to consume in proportion to actual needs by appealing to the imperative of [match practices to wellbeing](#); (2) What we **want to do** is resist technologies that push more consumption that we may not even need or want; (3) What we **can do** is (3.1) design systems or controls to degrade or increase resolution according to actual use, (3.2) arm people with an understanding of resolution and how misinformation about resolution is used to drive consumption, and (3.3) promote aesthetics of resolution as a style, rather than a quality in order to avoid the unsustainable belief in ever-increasing *high quality*. What we **can know** is what resolutions are required in which contexts to meet the authentic needs people, and when resolutions may be degraded without loss of experience.

Conceptual Design Scenario: A Digital Day of Rest

Figure 7 is reproduced from [5] with permission. The image shows an escalator that has been turned off on a Sunday when it

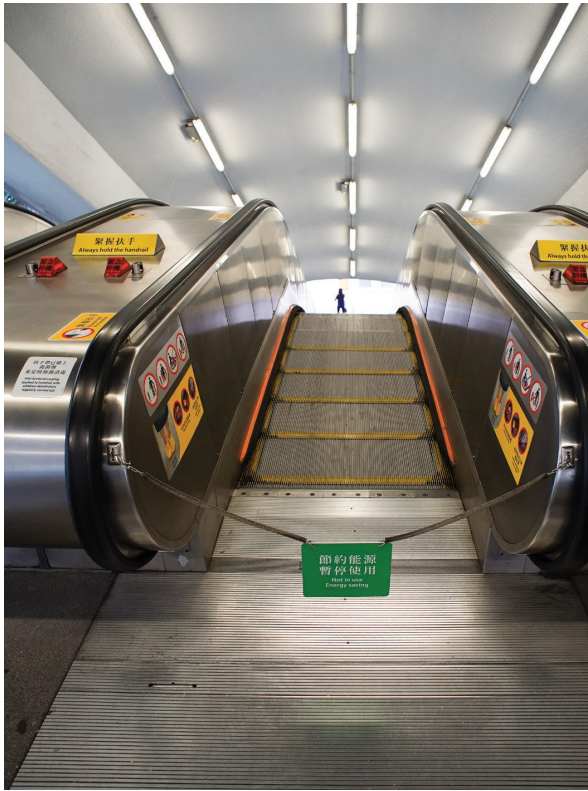


Figure 7: Not in use, energy saving (image © E. Bleviss)

would otherwise see little use. The sign reads “*Not in Use, Energy Saving.*”

It makes sense, as a matter of civic policy and resource conservationism to turn off an escalator at times when it would receive little use. In this case—but not in the image, there are two alternatives that permit ascent and descent when the escalator is in its “*not in use, energy saving*” mode. There are stairs. As a matter of accessibility, there is also an elevator near this escalator. Clearly, a municipality that can afford such structures is already privileged in its access to infrastructure.

Figure 3 is reproduced from [5] with permission. It shows a different scene in a different part of the same municipality pictured in Figure 7. It is also taken on a Sunday. This is a busier part of the city. A single direction escalator affords ascent to a harvest of patrons. Ascent and descent by means of the stairs is blocked by a Sunday gathering of migrant domestic workers. The joy of day-off conversations can be read in the faces of these women—they are *all* women—by the glowing light of smartphones and tablets. The physical waste papers and packaging strewn about the stairway—the result of an appropriation of the space for other than its designed intentions. This appropriation suggests that there are not enough better, more suitable spaces to service the needs of this population. There is a gender and class politics here that have long become invisible *in situ* to most of the migrant domestic workers, citizens, and others who cohabit this space.

The idea of a day of rest does not appear very much in the HCI literature, as far as we can ascertain. There is Woodruff et al.’s

[53] work on technologies that support Sabbath day religious obligations. Gaver et al. [18] have also contributed *critical design* in support of prayer, not specifically focused on a day of rest. The idea of disconnecting from technology does enter into the HCI discourse increasingly (e.g. Håkansson & Sengers [19], Pierce [38], Sengers [43], Simm et al. [45]).

We do not raise the issue of a *day of rest* embedded in the scenes of these figures specifically as a matter of belief or faith, nor as a matter of inequalities of class, nor as a matter of feminist perspectives (in HCI, see *for example* Bardzell [1,2], Forlano [16]—apropos of design targeted in the service of sometimes marginalized populations, and in [16] that “*privilege[s] reflection in order to raise pressing questions about alternative possible futures*”). These are critically important perspectives. Notwithstanding, our point here is to ask a question about the differences between how infrastructure plays a role in the world and how digital infrastructure plays a role in the world.

The decision to stop the escalator on Sundays does not rely on individual behavioral change. Rather, it is a public policy decision. Public compliance is not an optional act of an enlightened, sustainability-minded few, but rather affects everyone equally regardless of commitment to sustainable behaviors. The escalator has been turned off and simply can’t be used on this Sunday.

Those who find their descent blocked on the stairs in Figure 3 would be best not to blame the domestic workers who have nowhere else to spend their day of rest. Rather, it is a matter of public policy to provide spaces that are better suited to repose. Asking these workers to voluntarily leave the steps on their Sunday holiday does not make any sense unless there is a more suitable place to be. Providing such a space is also a matter of public policy and equitable distribution of resources, rather than individual behavioral change.

A *day of rest for digital connectivity* might be imagined along these lines. First, legislate the digital infrastructure equivalent of turning off the escalator—that is make it a matter of policy to have a day of rest or rolling days of rest from the internet. Second, make certain that there are better suited alternative places to be engaged than everywhere connected—that is a public, political responsibility.

Nowadays, many of us are connected to digital infrastructure all of the time—digital infrastructure is 24/7. So, what do we ask when we ask—*what would it mean for there to be a day or rest with respect to digital infrastructure?* Can we even ask such a question? That depends on how you understand sustainability, in its connection to HCI or generally. In our view, one cannot do better than to follow Nathan and Meyers’ recently stated notion: “... *what sustainability is at its heart: a negotiation of what we value and what kind of world we want to create.*” [30]:57.

Nathan and Meyers further argue that such negotiations must take on a mass *consumer* scale. That is similar to what we suggest here, except perhaps that we are arguing that scale requires a focus on the all and many actors, consumers and consumption-inducing enterprisers and their staff implicated not just in enterprise, but also in public policy. Like Nathan and Meyers, we

are arguing in this discussion that focusing on individual behaviors rather than scale of this sort does not have the reach to achieve broad sustainability goals. Others have argued for this shift in perspective as enumerated in the introductory section of this paper.

The SID paper was motivated in part a decade ago by Tony Fry's various writings (e.g. [17], see also Willis [52]) about how design in the perspective of sustainability is inherently political—that is, inseparable from policy. Dourish [13] later raises similar issues within the HCI literature. So, in some sense this discussion reminds us in the HCI community of that principle—*of the inseparability of politics and design*—a principle which seems less and less radical as the arctic ice recedes more and more (see IPCC [24]).

A day of rest from digital infrastructure is an extreme proposal that to some may seem more provocative than practical. Notwithstanding, while compliance with a day or rest for the internet is for all intents and purposes unimaginable, the global reduction of energy use could be extraordinary. This radical, and almost certainly impossible, proposal would allow devices to actually be switched off rather than merely remaining idle. How can more pragmatic versions of this be created?

Individually chosen *digital detox* periods are already spoken of, but how can community practices, and organizational or national policies be used to support such rest periods? A community practice can result in such a *rest* period. For example, Chinese academics have a clear tradition of communal lunch which is lacking in western academics. The Spanish *siesta* is another familiar example. Organizations may choose to impose such periods, for reasons of worker wellbeing or other reasons. For example, some companies shut down their phones and email systems for periods outside of work hours, even if people attempt to stay in the office. Partly to prevent fraud, and partly to encourage real holidays, some finance companies enforce several weeks of email-free time for their workers. Some people leave their smartphones in airplane mode most of the time—at least, two of the present authors are an existential proof.

Particularly with respect to the OCGQ imperative of [match practices to wellbeing](#), a day of rest—or time away from digital infrastructure may lead to more sustainable, healthier, and higher quality lifestyles. Particularly with respect to the OCGQ imperative of [consider resilience & preparedness](#), a digital day of rest would help establish preparedness of the possibility of interruptions to core infrastructure. Those risks are described in Tomlinson et al. [47,48,49].

Apropos of the TDF, we may understand this discussion's imperatives in the following ways: (1) What we **must do** is live within sustainable limits with respect to infrastructures, digital or otherwise, that is the OCGQ imperative of [consider resilience & preparedness](#), while also promoting a healthy relationship between people and their reliance on technologies per the imperative of [match practices to wellbeing](#); (2) What we **want to do** is distribute infrastructure fairly and within limits; (3) What we **can do** is consider if it is remotely feasible by policy or by accord or voluntary means to establish rolling “digital Sabbaths”

to reduce use, while providing rest to people, and lowering overall digital infrastructure demand; (4) What we **can know** is how much energy is/may be saved were such a system in place.

SUMMARY

In this paper, we synthesized various frameworks from SID and SDID, yielding a summary of four overarching questions to guide our discussions of three conceptual design scenarios—one concerning a conceptual prototype, one concerning how to raise understanding of the effects of resolution choices on resource use, and one concerning the extreme concept of a digital day of rest. Our hope is to continue to advance the connection between SID and SDID by prompting others to contribute additional conceptual design scenarios shaped in this way, and to do so ourselves.

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SUPPLEMENTARY MATERIALS APPENDIX: INVENTORY OF SID/SDID CONCEPTS

Inventory of Analytic and Concept-generative Principles and Frames

The inventory of principles and frames in this table owe to various sources, but especially the SID and SDID papers. Collecting them all together here is essential to enable this paper to stand alone for review, but should not stand as a substitute for the original sources—the original sources provide more detailed discussions about the origins of these lists and illustrative examples of how they may be applied. This inventory is in a key sense a reporting of prior research germane to this paper. It is also an aggregation into a consistent naming scheme.

For complete accounts, please see

SDID

Chris Preist, Daniel Schien, and Eli Blevis. Understanding and Mitigating the Effects of Device and Cloud Service Design Decisions on the Environmental Footprint of Digital Infrastructure. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (CHI '16). ACM, New York, NY, USA, 1324-1337.

SID

Eli Blevis. 2007. Sustainable interaction design: invention & disposal, renewal & reuse. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (CHI '07). ACM, New York, NY, USA, 503-512.

SID-Principle: *Sustainable Interaction Design Principles*—The SID paper introduces five design principles that are intended to serve as high level goals of sustainable interaction design. They are:

- 1 Linking invention and disposal
- 2 Promoting renewal and reuse
- 3 Promoting quality and equality
- 4 De-coupling ownership and identity
- 5 Using natural models and reflection

SDID-Principle: *Sustainable Digital Infrastructure Design Principles*—The SDID paper introduces ten design principles in this same style that are intended to serve as high level goals of sustainable digital infrastructure design. These are:

- 1 Linking infrastructural expansion and obsolescence
- 2 Promoting infrastructural use-efficiency and sharing
- 3 Promoting reliable infrastructure from sustainable sources
- 4 Promoting equitable distribution of bandwidth
- 5 Promoting online/offline life balance
- 6 Eliminating wasteful use of infrastructure
- 7 Making infrastructure use transparent
- 8 Computing within limits

RoIE-Cornucopia: The SDID paper provides an initial frame that identifies a number of assumptions about the criteria for an economy of infrastructure that follow from the tragic belief that infrastructure resources are limitless. These are:

- 1 Personal
- 2 Variety
- 3 Instant
- 4 Sharable
- 5 High quality
- 6 Pervasive
- 7 Continuous access
- 8 Eternal
- 9 Ephemeral
- 10 Rich, cross-modal, and ubiquitous

RoIE-Infrastructure: *Infrastructure Design Rubric Questions*—SDID:

- 1 Does the design encourage deployment of qualitatively new infrastructure?
- 2 Does the design actively stimulate the need for change/obsolescence in the existing infrastructure?
- 3 Does the design actively stimulate the need for expansion in the existing infrastructure? Does it result in a step-change in demand for infrastructure services?
- 4 Does the design encourage additional use of the existing infrastructure than currently takes place? Or is it likely simply to substitute for a different use of similar intensity?
- 5 Is the design flexible, or fixed, with regard to its use of the infrastructure at times of peak demand?
- 6 Does the design encourage or discourage *digital waste*?
- 7 Does the design encourage use of lower bandwidth modalities within it, or does it default to high bandwidth?
- 8 Does the design encourage the use of lower bandwidth modalities to substitute for higher bandwidth ones?
- 9 Does the design encourage sharing of infrastructural use, to reduce pressure on the infrastructure?
- 10 Does the design encourage an awareness of the use of infrastructural resources by the user, or does it hide this, promoting the sense of unlimited availability?

RoME: *Sustainable Interaction Design Rubric of Material Effects (RoME)*—The SID paper also introduces a rubric of material effects that is essentially life cycle analysis (LCA) adapted to the particular circumstance of interaction design and its associated devices. The RoME—ordered approximately from least sustainable to most sustainable—is

- 1 Disposal
- 2 Salvage
- 3 Recycling
- 4 Remanufacturing for reuse
- 5 Reuse as is
- 6 Achieving longevity of use
- 7 Sharing for maximal use
- 8 Achieving heirloom status
- 9 Finding wholesome alternatives to use
- 10 Active repair of misuse.

SUPPLEMENTARY MATERIALS APPENDIX: INVENTORY OF SID/SDID CONCEPTS

<p>RoIE-Limits: <i>Computing within Limits Design Rubric Questions—SDID:</i></p> <ul style="list-style-type: none"> -1 If this service were to be used by all the world's population, what would the overall environmental impact of the infrastructure be? Can we imagine a future scenario where this would lie within limits imposed by planetary boundaries? -2 Is the service able to deal robustly with reduced availability of infrastructure levels? -3 Does the business model assume continued growth in infrastructure? If so, what is the risk associated with this? 	<p>RoIE-Collapse: <i>Collapse Design Rubric Questions—SDID:</i></p> <ul style="list-style-type: none"> -1 What is the societal value of the proposed service, and in what scenarios of restricted infrastructure would this justify the resultant usage? -2 Can a restricted version of the service be imagined, and what would its value and infrastructural burden be? In what collapse scenarios would this be deployable? 	<p>RoIE-Responsible: <i>Responsible Design/SHCI 2.0 Design Rubric Questions—SDID:</i></p> <ul style="list-style-type: none"> -1 Does the service encourage a healthy relationship with digital technology, and avoid promoting inappropriate dependency on the digital infrastructure? -2 Is the service in tune with your values, as a designer? Can you say with heart that the benefits it brings humanity is worth the environmental costs of the supporting infrastructure?
<p>Trends: In the introduction to this paper, we described a frame of issues and trends in SID/SHCI. These form a frame as follows:</p> <ul style="list-style-type: none"> -1 Invention and disposal: new and old -2 Political economy: shifting responsibility -3 Levels of design focus: (3.1) individual & behaviors, (3.2) communities & practices, and (3.3) governance & policy <p>TDF: <i>Transdisciplinary Design Frame—we provide the following frame from transdisciplinary design theory:</i></p> <ul style="list-style-type: none"> -1 Must do -2 Want to do -3 Can do -4 Can know 	<p>OCGQ: <i>Overarching Concept Generative Questions—we appeal to these question in this paper to unify this inventory of SID and SDID frames:</i></p> <ul style="list-style-type: none"> -1 Understand & Reduce: How can we understand and reduce the negative environmental impacts of existing practices supported by the technologies we design, while taking human wants and needs into account? -2 Uncover Assumptions: What implicit values and assumptions are embodied by the practices our technology encourages which result in environmental impacts? Can we make these explicit, provide alternative perspectives, and encourage alternative practices in designers and people? -3 Match Practices to Wellbeing: Do the practices encouraged by the technology support or work against the wellbeing of the individual and society? What can be done to mitigate this or promote alternative practices? -4 Consider Resilience & Preparedness: Are the practices encouraged by the technology resilient to future environmental and societal challenges we may face? Do they encourage preparedness? 	