Sustainability in (Inter)Action provides a forum for innovative thought, design, and research in the area of interaction design and environmental sustainability. The column explores how HCI can contribute to the complex and interdisciplinary efforts to address sustainability challenges.

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Sustainability *Does Not* Begin with the Individual

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In the past decade, an increasing amount of HCI research has been concerned with making personal and household environmental impacts (such as energy, water, or CO_2 equivalents) more *visible*, with the aim of educating people and affecting their relevant actions. We have two concerns with this. First, when evaluated "in the wild," the scale of reduction achieved tends to be limited to less than 10 percent (of, say, household electricity or water) and is not proven to be long-lasting. This result is the same as for interventions trialed over the past four decades, many of which employed low-tech methods such as itemized or more frequent energy bills [1].

One surface reason for this is that with the current relatively low energy and water prices (particularly in the U.S.), the money each household would save by changing its behavior is negligible. For example, in a study of computer power management using logged data from participants' computers, Chetty et al. estimated that even with an oracle that reclaimed all wasted power, the average annual savings would be $4.75 (U.S.) per desktop computer and $0.24 (U.S.) per laptop [2]. These small values matched participants' perceptions that turning off their computers would not save much money.

Our second concern about eco-feedback, visualization, and persuasion is more fundamental. We think these approaches are limited because making significant, lasting reductions reaches far beyond an individual's (non)reactions to real-time information on resources. Infrastructures, technologies, competencies, social relations and expectations, and what are taken to be "normal" ways of living tend to dominate the picture. Others have recently articulated these arguments from different standpoints, and we recap a few here.

Strengers argues that even if eco-feedback is correctly interpreted and analyzed by users, it may not be acted upon because of negotiation among household members, people's shifting expectations and increasingly resource-reliant aspirations, and because many existing practices are seen as non-negotiable or taken for granted [3].

Brynjarsdóttir et al. develop a critique that persuasive approaches tend to be limited to focusing on measurable and displayable quantities (such as electrical energy). Other important factors, such as social expectations or perceptions of what is normal and necessary, are not taken into account, and thus interventions turn out to be ineffective and/or short-lived [4].

To sum up, we think that many eco-feedback and persuasion approaches implicitly draw upon models that conceptualize society as a collection of *individuals* who have a set of values and attitudes and exhibit certain behaviors, which are manifested by their conscious choices. In the reality of everyday life, this approach doesn't work well [5], because it assumes people have the time, competency, and technology/infrastructures, and will juggle sustainability with significant competing concerns (such as expectations from family and employment, or embedded social meanings such as keeping a comfortable home) in order to be able to make and execute choices to achieve reduction.

Instead, we argue that the HCI community is particularly well situated to think about how *technologies* (devices, systems of devices, and the services they provide) can be redesigned, leading to reductions not predicated upon a concept of individuals who make constant and active choices.

Reduce the Resource Reliance of Existing Devices and Services

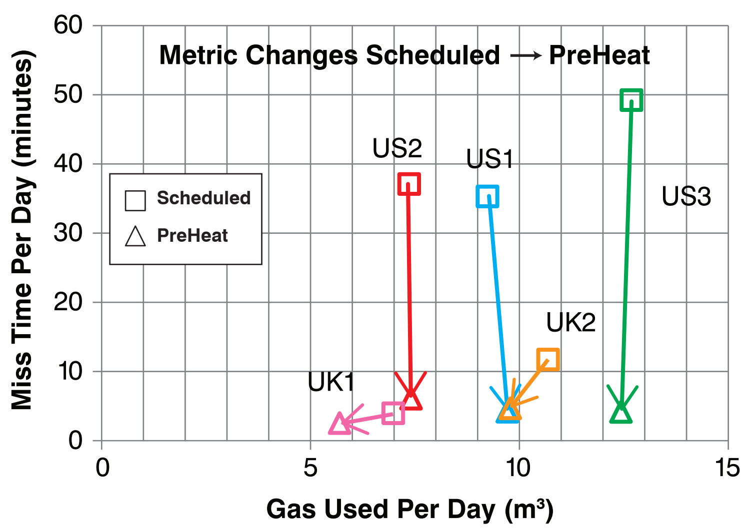
As a case study, consider the service of home heating, which draws more energy than any other U.S. residential energy expenditure, including air conditioning, water heating, and appliances [6]. Fundamentally, home heating is a trade-off between energy use and warmth. Rather than "nudge" occupants to more actively manage their thermostat (i.e., change their behavior), we reengineered the heating system to use sensing and prediction. Our system, PreHeat, uses occupancy sensors to maintain the desired temperature whenever people are present, and during absence uses past occupancy patterns to predict future occupancy and heat up the house just in time [7].

Our deployment of PreHeat in five homes, three in the U.S. and two in the U.K., in the winter of 2011 was encouraging. We observed energy savings of more than 10 percent in four houses, compared with always leaving the thermostat on at a particular temperature (a choice made by a surprising number of U.S. households). The final home was occupied the majority of the time, limiting the potential for savings. In the U.K., where per-room heating control was possible, we also saw 18 percent and 8 percent energy improvements, compared with the families' best seven-day thermostat schedules (27 percent and 35 percent savings over always on; see Figure 1). These savings were realized without causing participants discomfort; in fact, PreHeat decreased the amount of time people were home and felt the temperature was lower than desired by 38 to 92 percent.

PreHeat makes these savings without requiring any action by users; however, additional savings may be possible with user interaction. The use of sensing and prediction also raises some very interesting HCI challenges. For example, PreHeat makes a trade-off between the likelihood of the house being cold when someone arrives and the amount of energy used. Figuring out the best user interface to expose this trade-off to residents in an understandable manner so they could specify what they prefer (saving money or having a warmer home) could lead to even greater energy and money savings in some households.

While heating accounts for a large share of the impacts in many societies, other contributors that could benefit from changes in technology include electrical appliances and water. In fact, home electronics (specifically media, entertainment, computer, and other IT devices) can compose a significant share of a household's consumption. In a detailed study with university students in the U.K., we found that in two of four flats, the electrical energy involved in providing the "services" of entertainment and IT comprised 17 percent and 34 percent of the total flat-wide energy [8]. This put it roughly on par with the other two major electricity-supported services that we observed: cooking/refrigeration (20 percent to 25 percent) and lighting (16 percent).

And yet, in the other two flats, we noted dramatically less energy directed toward entertainment and IT (3 percent and 6 percent). From participant accounts, we know the associated devices across the four flats were used and valued in similar ways: doing university coursework, reading the news online, social networking, watching TV, and playing games. The difference? The nature of the devices deployed. In



▸ Figure 1. Compared to setting a daily schedule with a programmable thermostat, PreHeat saved 8% and 18% on gas usage in the two U.K. homes. In the three U.S. homes, PreHeat did not save as much, but rather used the gas more effectively: It was less likely the house would be below the set temperature while occupied (Miss Time on the *y* axis).

High-impact areas (indoor climate, travel, food, and purchases) are particularly challenging, precisely because they are so technologically, socially, and culturally mediated.

the flats where electronics made up a larger proportion of the energy share, there tended to be constellations of devices connected together: desktop PCs, multiple monitors, external hard drives, digital set-top boxes, game consoles, large-screen TVs, and home-cinema amplifiers. In the flats where it made up a much lower proportion, the only device connected in most of the bedrooms was a single laptop.

This illustrates the hand that design plays in the resource-reliance of a technological artifact. Highly portable electronics such as mobile phones, tablets, and laptops have been designed and hardware/software engineered to draw minimal power and maximize battery life. What would happen if the same priority were assigned to energy efficiency in all appliances used for entertainment and IT? Much lower power devices are certainly achievable; we point as an example to EU regulations that have driven typical standby consumption from tens of watts to less than one watt per device (typical).

Picking Your Battles: Reductions in Context

However, it is important to consider how these reductions scale, and in the grand scheme of total energy and carbon. For example, if we were to deploy PreHeat throughout the U.K. both at home and at work, and assume that it saves about 15 percent on heating energy, then total national energy consumption would be reduced by about 1.8 percent [9]. Or, suppose the U.K. embarked on a national campaign to reduce appliance and lighting energy by insisting on lower-power (perhaps smaller) TVs and media players/consoles, mandating laptops instead of new desktops, enacting power-efficient default settings for all appliances, and making most lighting occupancy-reactive. According to our study in the four flats, this might save as much as 50 percent of electrical energy for lighting, media, and IT… resulting in a total U.K. savings of 2.3 percent [11].

On the face of it, these numbers are discouraging. Scaling such interventions to an entire nation would be challenging, and the potential reductions are well short of targets such as an 80 percent emissions reduction by 2050. However, we argue there is value in truly scalable reductions of a few percent of the total energy usage or carbon emissions. First, different efforts can be complementary, and resulting reductions may add up. And second, by identifying and investigating the areas having the most impact, we can put together important pieces of the puzzle showing the composition of consumption across societies, and how it can be shifted to lead to the kinds of larger reduction required.

To be relevant and fruitful for sustainability, it is crucial to look at the composition of energy and/or emissions for the particular context of interest (including people, technologies, and locales). In most parts of the U.S. and the U.K., for example, there are four areas that have a relatively high impact. We have already discussed the indoor climate. A second is that of *transportation*: private cars, commercial airplanes, and to a lesser extent, mass transport like trains and buses. A third high-impact area (particularly in terms of its carbon emissions) is that of *food* production, storage, and distribution. And the fourth high-impact area is that of the *stuff we buy*—particularly stuff manufactured and transported from overseas. The effects of these are difficult to estimate (even with detailed life-cycle analysis), but invariably "stuff" makes up a large part of the balance—by some reckonings, over 25 percent in the U.K.

Just as Mankoff argued in a recent contribution to this forum (May + June 2012), it's important to consider applicability for the context of interest [12]. There are parts of the world where cycling or public transport is simply not a workable option for many lives as they are currently configured. Electric cars might have lower carbon emissions, but many people do not consider them financially or practically viable. And although it's true to some extent that people may be encouraged to opt for lower-impact purchases and travel, we suspect that in isolation, "assistant apps" for lower-carbon shopping and transport will be quite limited in their sustained reductions, for reasons similar to those given for eco-feedback and persuasive approaches.

Reconfigure Technology, Service, and Practice

These high-impact areas (indoor climate, travel, food, and purchases) are particularly challenging, precisely because they are so technologically, socially, and culturally mediated. So these might be most effectively addressed in conjunction with policy initiatives and broader public support. But HCI should anticipate and lead these future trends, look for opportunities to raise awareness in meaningful ways, and open up debate. For example, the ethnographic expertise of HCI can offer valuable insight into where practices, and their associated expectations of resource-reliant services, are headed. Devices such as smartphones, e-readers, tablets, and laptops are increasingly interwoven into everyday life. How do these devices enable, encourage, or constrain things like shopping for food, making purchases, and organizing travel? What implication does this have for emissions and energy?

Such deeper understandings enable us to better conceive of technologies and infrastructures that are more subversive, perhaps working to slowly change expectations over time, or constrain interactions resulting in lower-impact services [13]. For example, it is increasingly common for modern washing machines to default to a lower temperature setting. Imagine a PreHeat system that is not only occupancy-predictive but that also sneakily lowers its temperature setting at selected occupied times, learning the occupants' tolerance (and even preference) for reduced temperatures.

In our observations of energy-reliant practices of university students, we frequently saw practices that entailed concurrent and adjacent use of services [8]. The lower-resource activities of watching TV or playing video games would overlap with higher-impact activities such as cooking and showering. Many everyday practices were organized around sometimes conflicting university, employment, social, and family schedules. For busy lives like those of our participants, quickness, convenience, and spontaneity dictated the options for things like food, transportation, and even entertainment. This motivates redesigning technologies to achieve finer-grained energy savings. For example, turn off a video screen, leaving the sound on and media still playing if nobody is looking at it (as they multitask on something else). Or make default appliance behaviors the most energy-efficient in the face of spontaneous and convenience-oriented use.

Moving Forward

Looking at the growing amount of sustainability research not only in the HCI community but also across many disciplines, we are excited about the potential for impact reduction. We think the biggest opportunities emerge when people work together across these areas, rather than in silos. Researchers working in HCI are well suited to help address the tricky interaction problems that arise when systems (like heating) are reenvisioned, and also have a deep understanding about the construction of needs and contexts of people. More bluntly, we want to see the creativity and expertise of the sustainable HCI community rethinking, reimagining, and creating new approaches to tackle challenges of resource and carbon reduction, rather than the community confining its interventions to visualization and persuasion based around the status quo.

ENDNOTES:

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9. This is based MacKay's 2009 analysis which puts indoor heating's share at 24 out of the total 195kWh per person per day [10]. The total includes the embodied energy of the stuff we buy. Conversion of energy (both embodied and direct) to carbon equivalents is complex and varies highly with locale. So we'll stick with these energy-equivalent numbers, as an illustrative example.

10. MacKay, D.J.C. *Sustainable Energy—Without the Hot Air.* UIT Cambridge Ltd., 2009.

11. This uses MacKay's (2009) total of 9kWh per person per day for "gadgets" and "light."

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DOI: 10.1145/2334184.2334189