Solar Protocol: Exploring Energy-Centered Design

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ABSTRACT

Solar Protocol is an experimental web platform hosted across a network of solar-powered servers, installed and maintained by volunteers in different locations around the planet. Although a solar-powered server's connectivity is intermittent as it is powered by available sunlight, when connected in a network, the network can be designed to direct web traffic to whichever server is enjoying the most sunshine at the time. In doing this, *Solar Protocol* uses the distribution of sunshine across the planet as a form of logic that determines where computational work is done. By automating decisions according to environmental dynamics, the project explores a kind of "natural" intelligence rather than artificial intelligence. *Solar Protocol* works in concert with limits defined by local energy availability and thereby explores an energy-centered design. We sketch out six principles of energy-centered design, offering these as provocations for further work.

KEYWORDS

design, art, web development, sustainable HCI, artificial intelligence, resilience, networks, follow-the-sun computing.

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1 INTRODUCTION

Solar Protocol is an artwork and design intervention exploring the affordances of solar-powered computing networks. The project takes the form of a planetary-scale network of solar-powered web servers, stewarded by volunteers around the world. A solar-powered server is a single-board networked computer, powered by a small solar panel and battery, and due to the limited size of its energy system, its capacity to serve a website is intermittent. As the solar-powered website of Low-Tech Magazine has demonstrated, sites hosted on such systems will "sometimes go offline" [11]. However in *Solar Protocol*, when these kinds of servers are connected in a network that spans the planet, they can coordinate to collectively serve a website (www.solarprotocol.net) from wherever there is the most sunshine [7]. See the illustration in Figure 1. The project therefore uses the distribution of sunshine around the planet to automate decisions about both scheduling tasks on servers, producing temporal flexibilization of demand, and load balancing across the network, producing spatial flexibilization of demand. In doing this, *Solar Protocol* demonstrates "follow-the-sun" computing [19].

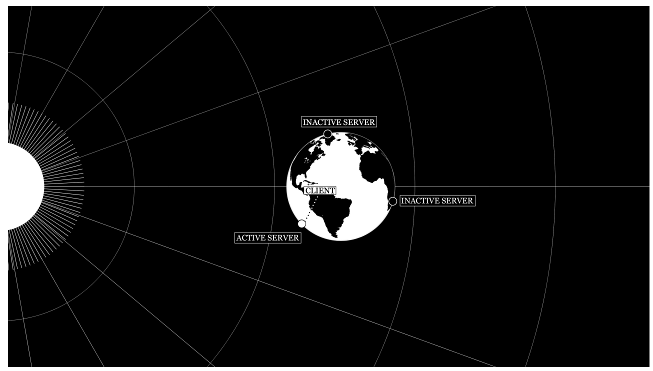

Figure 1: The *Solar Protocol* servers are located in different time zones, the website is served from whichever is in the most sunshine.

Solar Protocol has grown from a small-scale design experiment to an international prototype consisting of ten servers, each hosted and operated by stewards across six continents. We call our collaborators, "server stewards", in reference to environmental and infrastructural stewardship that emphasizes relations of care and maintenance, and following Taeyoon Choi and collaborators who used this terminology in their project, Distributed Web of Care (2018) [8]. We recruited stewards through an open call on the project website and through our personal networks. As shown in Figure 2, stewards mostly assembled their own server from locally sourced parts with remote support from our team.

Although work on this project is ongoing, it is a fully realized implementation of a distributed, community-owned web hosting system, powered by renewables. It provides solar-powered web hosting for server stewards and it currently hosts several websites and educational resources. In this way, we envisage it as a kind of virtual artist-run space that will continue to host art and design projects in the coming years.

As a design intervention, we hope to furnish new imaginaries for solar-powered systems by exploring their affordances and limitations as productive creative constraints. We aim to further thinking and design work on reducing the energy demand and climate impacts of ICTs, UX design practices and online visual culture and explore questions such as: What might follow-the-sun computing look like? How might this approach address issues of intermittency in solar-powered computing systems? How does using the sun or the climate to automate decisions, instead of an AI agent or an

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algorithm, provoke new ways to think about automation and intelligence? How might the internet change, if it were solar-powered and energy were a primary consideration?

Figure 2: Steward Graham Wilfred Jnr constructing a solar-powered server in Alice Springs, Australia.

This paper examines these questions by discussing the decisions we made in building *Solar Protocol*. We also share some key concepts that emerged through the making of this project, that of designing with natural intelligence and energy-centered design.

2 BACKGROUND

Solar Protocol responds to many issues that have been identified by the LIMITS community relating to the energy impacts of online experiences and the digital infrastructures that support them. These include designing computing systems in view of the intermittency of renewable energy sources [5], in ways that enable the "flexibilization of [energy] demand in space or time", [19], that attempt to communicate their materiality in both media and education contexts [23] and that explore how the environmental footprint of digital infrastructure (such as data centers and network technologies) might be attended to or mitigated [29].

We also build on precedent creative work exploring the aesthetics and materiality of internet technologies and "the cloud". It responds to provocations made in the Feminist Server Manifesto 0.01, where ideas from feminist theory related to the importance of acknowledging embodiment and the situatedness of knowledge production, are considered in the context of internet technologies [1]. As mentioned, the project also extends the work of Low Tech Magazine, whose Solar-powered Website (2018) demonstrates how a web interface can both visualize the typically invisible energy characteristics of the server and offer a striking reminder of the situatedness and materiality of computing. We also take inspiration from projects by artists Michael Saup (2010) [30] and Joana Moll (2014) [24] who estimate the significant energy implications of online services like Youtube's video streaming and Google's search respectively and present the results in visually engaging ways.

Solar Protocol is a functional creative experiment with small scale solar-powered servers. These kinds of servers are valuable for hands-on prototyping, design experimentation and building digital literacy. They provide a way to think outside of the technological status quo which is profoundly influenced by privately owned cloud companies who encourage computing to be imagined as immaterial and infinitely scalable and by what Preist et al. calls the "(undesirable) cornucopian paradigm" of interaction design, where services are expected to be instantly and continuously available, personal, and ubiquitous [29].

However, the project does not offer a way to opt out of the infrastructure of the internet. Stewards require internet access via an ISP to connect their server which then relies on core and edge networking technologies to communicate (network infrastructures themselves have significant impacts and were estimated to consume 1.7% of total global electricity use in 2021) [25]. Therefore, *Solar Protocol* does not propose a strategy of retreat. Rather, as technology writer Jenny Odell puts it, by "participating in the 'wrong way': a way that undermines the authority of the hegemonic game…[it] creates possibilities outside of it" [26]. In doing this, small solar-powered servers also offer a way to probe the ontological possibilities of designing in energy-centered ways, where changing energy production and reducing energy demand provide opportunities for developing new ways of working and living. And so, despite what some of the press coverage of *Solar Protocol* has reported [10], we don't offer this work as a neat solution to the problem of the growing energy impacts of the internet but rather, intend the project to be a provocation to scrutinize, examine and explore ways of reducing these impacts. *Solar Protocol* therefore continues in the tradition of art technology practices like interrogative design [33], critical [27] and eccentric engineering[32] and rhetorical software [3], all of which blend technical experimentation with speculation and cultural commentary.

3 DESIGNING SOLAR PROTOCOL

3.1 Hardware

Solar Protocol relies on a standard off-grid PV system that includes a 50-watt (W) photovoltaic (PV) module, a charge controller, 22 amp hour (Ah) sealed lead acid battery, various overcurrent protection devices, and a low voltage disconnect for the battery. The hardware was chosen for its ready availability so that stewards could source parts locally in different parts of the world. While more specialized components would have made the servers more electrically efficient, shipping them would have been challenging, expensive, and carbon intensive, this is especially true for batteries. Where 50W modules have not been available, slightly different modules have been used, and their data is scaled to be comparable with different sites.

The battery for each server is sized to accommodate roughly 24 hours of activity, which means the server will shut down if it is without sun for more than one day. The time to recharge depends on the weather, length of day, orientation, and obstructions. While a bigger PV system would reduce individual server downtime, we were specifically interested in constraining the module and battery size to reduce cost, minimize embodied energy, and have the system rely on dynamically distributing load to where solar energy is available, (what we call the solar protocol).

The charge controller data collected at each server shows that the total electrical load is generally less than 3W and periodically peaks at nearly 5W. With the draw from all the components, we conservatively estimate that the system consumes a maximum of about 100-watt hours (Wh) per day. Ideally the PV module produces this much energy per day and the battery must be able to supply at least 8.29Ah.

Most systems in the network use a 22Ah battery and to prevent over-drawing, the battery protection device disconnects the electrical loads when the battery dips below roughly 45% capacity and turns them back on when it is fully charged. In this context a 50W PV module requires about 3 hours of direct sun to store 12.1Ah, which is 55% of the total battery capacity. This assumes the charge controller operates at 96% efficiency [15], but it does not take into account site specific obstructions or other environmental variables. While a larger system could ensure that the servers have more uptime, we wanted to minimize costs and explore the constraints of working at a small scale.

It is worth noting that depending on the time of year, some of our most northern or southern sites may not have 3 hours of sunlight per day. In these instances, server activity shifts to sunnier climates. Additionally, many of our stewards do not have ideal installation sites and this means many of the PV modules are not oriented directly towards the equator and many sites have obstructions like neighboring buildings that block the sunlight for a portion of the day. As with many decisions in *Solar Protocol*, we were able to be less stringent about optimizing energy conditions at individual sites because of the network's capacity to dynamically shift energy demand. Our goal is not to completely mitigate downtime, but to minimize the chance that downtime will occur through this network behavior.

3.2 Software

Solar Protocol runs custom software for load-balancing, networking, and collecting energy data. There are six backend tasks that make up the core code base, these do the following:

- Collect energy data from the charge controller at 2-minute intervals.
- Post server data. Each server posts its IP address, timezone, and active server log, to all the other servers on the network. Almost all are on residential internet plans with dynamic public IP addresses, so this ensures that the IP addresses are up to date.
- Identify the active server (i.e the *Solar Protocol*). This determines if a particular server is the resolved destination for the network and will be the site for computation activity. Each server makes a call to all the servers in the network to retrieve their scaled PV power. If the server that originated the call is producing the most power it self-identifies as the active server, logs the event, and updates the DNS registry. This independent identification enables the network to work regardless of how many servers are online at a given time and be resilient to glitches. Even if multiple servers try to update the DNS records simultaneously because of an error, it won't break the system.
- Get energy data from all remote servers and store it locally.
- Static site generation. The public facing *Solar Protocol* website is a static site, where HTML and CSS pages are generated on the server rather than repeatedly in the browser every time a client requests the site. A static site allows the computational work required to generate the pages, to be scheduled for when energy is available [5]. HTML pages are generated with recent energy data from the PV system as well as custom content posted by the steward of the particular server. If energy stored in the battery is running low, the server will generate a low energy version of the site without images. This reduces energy demands by minimizing the data it has to send out, however its primary value is for communicating its precarious energy situation to website visitors.
- Generating graphics: Network and other data visualizations like the real time graph shown in Figure 3, are also generated server side. However, if the active server drops into low energy mode, these images are not displayed, and this script doesn't run. These processes are scheduled independently on each server and run at a frequency that is determined by available energy. They run at intervals that vary from 10 to 120 minutes to make energy demand temporally flexible. The more energy that is stored locally, the more frequently these processes run. The network also has a publicly available data API, that gives open access to the energy data being collected across the network. This provides another avenue for engagement and experimentation with *Solar Protocol*.

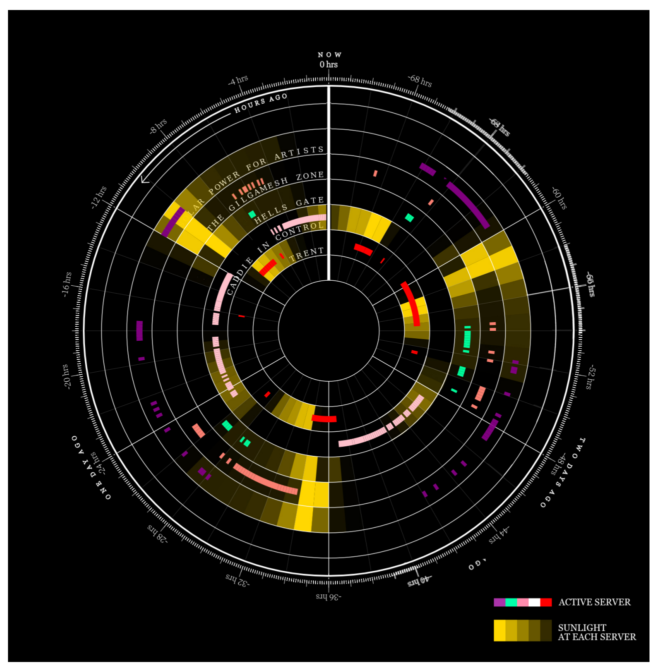

Figure 3: Screenshot from the www.solarprotocol.net of a visualization showing 72 hours of network data.

3.3 Network and Considerations of Scale

Access to solar energy across the *Solar Protocol* network is determined by the geographic location, module orientation, and local weather patterns at each server. In order for the network to be meaningfully programmed by the sun, it requires servers to be located across enough longitudes (i.e. time zones) so that some servers in the network are in daylight throughout most of a 24 hour period. This is what has determined the number of servers in our network. Latitude variation was also an important consideration as at different latitudes, the duration of the sun hours varies widely across the year and opens the possibility to explore seasonal as well as daily logics.

Presently, we have servers in Peterborough, Canada; New York City, USA; Philadelphia, USA; Santiago, Chile; Nairobi, Kenya; Newcastle, Australia; Alice Springs, Australia; Amsterdam, Netherlands; Beijing, China; and the Kalinago Territory, Dominica. The range of latitudes for these sites spans 52.3676° N in Amsterdam, Netherlands to 33.4489° S in Santiago, Chile. This represents a wide range of peak sun hours, hours where solar insolation averages 1000W/m2, across the network throughout a year. More network activity will occur in servers towards the northern hemisphere around the summer solstice, the southern hemisphere during the winter solstice, and the equator during the equinoxes.

Another notable constraint on the network has been a range of complex human factors. This has included both systemic issues of internet access and the hyper local challenges our stewards have faced like building management issues. In assembling the network, we were often subjected to the seemingly arbitrary whims and deceptive claims of ISPs relating to opening public ports on residential networks. Several of our collaborators also work at universities and tried to establish servers at these sites; however, they consistently found that IT administrators are reluctant to allow *Solar Protocol* to operate on institutional networks due to security concerns also related to opening ports. In working with our stewards on these challenges, as well as dealing with the government restrictions on internet access in China and the administrative controls of community-based networks in Dominica, the complex politics of internet access around the world has become very palpable.

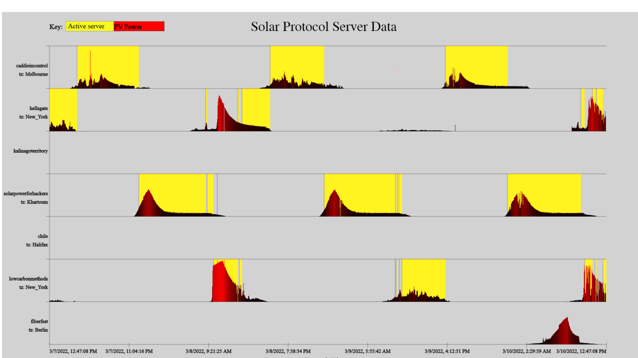

Figure 4: Server data from 72 hour period.

Presently, we have enough servers in different locations around the planet to see the network dynamics of the *Solar Protocol* play out as is shown in Figure 3 and 4. However, the long-term viability of *Solar Protocol* is ultimately tied to the community members that support it. We are intentionally working with a very diverse group who have wide ranging technical expertise, physical abilities, internet access, hardware access, and financial resources and who are media artists, media theorists, technologists, community organizations and directors of art spaces and university research labs. When a server steward is not supported by an institution, like a university, all hardware costs and an honorarium are provided through project funding.

4 ON THE POSSIBILITIES OF THE ENERGY TRANSITION

Many of the ways computation is currently used, particularly in an online context, result from an abundant supply of fossil fuel energy that in many places, remains subsidized by public funds[16]. Streaming media is estimated by some to account for 1 percent of global greenhouse gas emissions [22]. Machine learning systems demand tremendous energy resources [14] and are in wide use in the advertising business models of the web [34]. The expansion of the internet of things has also placed microcontrollers in machines like cars, blenders, dog feeders and ovens despite these devices long fulfilling their duties without being online. Does my juice maker really need to be on the internet to be able to serve its purpose?

The coupled expansion of computing and its energy demands continues to an absurd degree through web3 technologies, where computation is often expended for no use value whatsoever. Rather than being used in the service of weather forecasting, communications, or access to information, computers dedicated to cryptocurrency mining crunch numbers for the sake of crunching numbers. *Solar Protocol* and other works of solar or low-energy computing, raise questions of whether a solar-powered web would disincentivize some of these practices and the business models that go with them.

It's impossible to make claims about what the internet, and computation more generally, would look like if powered by renewables alone, but we speculate that it could foster the kind of energy centered design that we discuss in section 4 of this paper and lead to desirable shifts such as: less user surveillance; more privacy; platforms optimized for knowledge production rather than attention; less time spent doom scrolling; more time being engaged in in-person activities; wider use of static websites requiring less maintenance and updates; simpler, more transparent and therefore more durable software applications and more diverse business models than those built upon targeted advertising.

Solar energy technologies are not inherently more equitable or democratic without the intentional design of economic policy, regulation and legal frameworks to support these ends [6]. But they are a key part of lowering emissions, and in the process of transitioning towards the types of computational systems that renewable energy regimes can support, there are rich opportunities for reimagining and redesigning the ways we want computation to be in our lives.

5 BEYOND ARTIFICIAL INTELLIGENCE

By using sunlight to automate decisions in the *Solar Protocol* system, instead of an AI agent or an algorithm, we aim to provoke new ways of thinking about intelligence and automation. As historian Stephanie Dick argues, the history of AI has been characterized by a constantly changing definition of "intelligence". At its inception, AI research was largely concerned with symbolic AI, where the goal was to reproduce intelligent human behavior by automated means. Dick states:

> Perhaps most notably, human intelligence was the central exemplar around which early automation attempts were oriented. The goal was to reproduce intelligent human behavior in machines by uncovering the processes at work in our own intelligence such that they could be automated [13].

Throughout the twentieth century these commitments and approaches were discarded and today AI researchers are typically concerned with the techniques of machine learning [13]. In machine learning, the goal isn't to model human reasoning but to make predictions inferred from statistical models built from data, methods that are completely unlike human reasoning. Dick argues that today "most researchers want to design automated systems that perform well in complex problem domains by any means, rather than by human-like means… [something that] dramatically highlights the fact that what counts as intelligence is a moving target in the history of artificial intelligence" [13].

Considering this history, *Solar Protocol* suggests another way of thinking about intelligence. By using "natural" rather than artificial processes to automate decisions, it looks to the environment as a model for intelligence. It serves as a reminder that intelligence does not exclusively emerge from the human or from human-made machines. Seasons, atmospheric conditions, the rotation of the Earth, and other species, all have inherent intelligence and have always dictated human behavior and decision making, enabling and constraining our movements, food production and cultural activity. Natural intelligence is a prompt to design and automate in concert with these environmental forces and to attend to the diverse array of logics that have always defined our shared world.

The term "natural" is useful for disturbing the commonplace dualism already implicit in the term "artificial". Artificiality implies that humans and the biosphere are somehow removed from the operation of contemporary AI, an implication that strategically obscures both the exploitation of human labor as well as the environmental destruction crucial to its production [9]. However, we also acknowledge that the term is fraught and historically, has been used to justify violence and colonial dispossession. Brazilian architect Paulo Tavares describes this in the colonial violence against the indigenous communities of the Amazon Forest: "Figurations of the pristine, wilderness, the "green desert" and many other images of de-humanized nature…constituted [the] means by which the politics of erasure was perpetrated" [31]. We use the term not to try to claim some sort of neutrality or mask the political questions that inevitably arise when automating any sort of decision making. Nor do we use it to return to some Enlightenment fantasy that separates humans from everything else called nature. But it stands as a provocation for further work to expand how we account for intelligence.

6 ENERGY-CENTERED DESIGN

As we have seen, working with solar-powered servers catalyzes a need for designers and web developers to be directly engaged with the energy context of their work and go beyond the mainstream approach of human-centered design [28]. Designers like Anab Jain and Anne Galloway have pointed to the urgent need to expand the narrow focus of human-centered design and rather, design with an acknowledgement that humans are not separate from their ecology and depend on an intact climate and healthy ecosystems in order to thrive [20] [17]. Energy-centered design is one response to this challenge of reorienting design toward the ecological as it encourages designers to consider material context, explore energy affordances, communicate the energetic attributes of their work, acknowledge trade-offs and rescript design ideals. As design researcher Marloes de Valk (2021) discusses, there are many other schools of thought around computing and digital media that foreground its ecology and ethical use [12]. Approaches like degrowth [5], the interaction design rubric proposed to reduce digital infrastructure impact of Preist et al. [29] along with the principles of minimal computing resonate with our goals to catalyze thinking on energy-centered design and envisaging low carbon online culture [2]. Drawing on some of this work and what we have learnt through Solar Protocol, here we propose several prompts for realizing a more "energy-centered" design.

6.1 Make Energy Data Public

How can we better convey, communicate and visualize the often-invisible energetic attributes of computational technologies in user interfaces and online experiences? There are opportunities for both designing implicit relationships of form and function where, for example, energy availability might influence the size of assets or resolution of media, as well as for explicitly visualizing energy related data, for example the battery icon that indicates stored energy. The goal, however, is not to visualize energy data in order to frame energy impacts as challenges to be dealt with through individual behavior change. As climate writer Mary Annaise Heglar argues this "turns environmentalism into an individual choice defined as sin or virtue, convicting those who don't or can't uphold these ethics" and quickly turns into victim blaming [18]. Rather the goal is to foster energy literacy at the point of design and engineering, where those in these fields are encouraged to be cognizant of the effects of their decisions. In *Solar Protocol* we make the active server's energy data visible on the website and developed an open data API [4] to allow full access to the energy data of all the servers.

6.2 Design Energy Responsive Systems

Developing energy literacies in designers and developers is key if we are to develop energy responsive systems attuned to specific conditions. For example, can computational work be scheduled when there is renewable energy available? Can this work be postponed or minimized when fossil fuels are in use? An example of this temporal flexibilization of demand is shown by the Branch Magazine website that modulates the website resolution depending on the energy mix in the client's region [21]. Similarly can computational work be distributed to places where low carbon energy is abundant as is the case in the *Solar Protocol* network? Can demand be geographically distributed to reduce carbon emissions? Energy-centered design also considers how specific energy contexts are shaped not only by technical and geographic conditions, but also the legal, economic and social characteristics of an environment.

6.3 Account for Where Computational Work Happens

On the *Solar Protocol* network, computational work is done where energy is abundant, and it is minimized in places where energy is scarce. The use of a static site generator also means the pages and visualizations are generated on the server itself, rather than generated in the client's browser. These computational cycles are therefore powered by solar rather than potentially by fossil fuels. This inverts a capitalist logic that incentivizes the export of costs to someone else somewhere else, a drive that underlies the concurrent ecological crises.

6.4 Acknowledge Intermittency

Intermittency is a characteristic of renewable energy sources like sun and wind. It can introduce uncertainty, disruption and means infrastructures can't be so easily abstracted and forgotten. Designing resilient systems means designing with the intermittency of environmental conditions in full view. This might mean implementing the demand flexibilization strategies discussed, or by designing for what Abbing calls, heterogeneous use, that is, for "a heterogeneity of browsers, devices and connection speeds" [5]. This has the added benefit of also addressing the disparity in internet access around the world, for example, enabling caching or light weight offline versions of web content to be downloadable. This is also an increasingly urgent challenge at a time of climate breakdown and related disruptions.

Designing with intermittency also offers opportunities for redesign. How could this characteristic be used for shifting expectations and rechoreographing rhythms of work, rest and play to better match energy conditions?

6.5 Use Planetary Limits as Logic

Solar Protocol implements a system governed by an ecological protocol that automatically curtails operations based on the energy it can produce itself. As has been discussed, it explores automation not by artificial intelligence but by means of a natural intelligence derived from planetary dynamics. Considering planetary limits as logics for designing decision making in infrastructures offers us ways of moving away from extractive models of production and of designing increasingly self-sufficient systems. Treating the availability of sunlight as a form of logic for automating decisions about balancing computational work and routing web traffic also has the effect of reducing system downtime. It's always sunny somewhere.

6.6 Question Resolution

Energy-centered design questions the prevailing impulse to maximize the resolution of media and remembers that rich user experiences can be produced at all bandwidths. It is not a call for austerity, but it is the recognition that affect is not relative to pixel density. It is also not a call for climate fundamentalism, where emissions reductions and efficiencies are prioritized at the expense of all else [6]. Design for equity and accessibility is always worth it.

7 CONCLUSION

In this paper we have discussed the goals and the design decisions of *Solar Protocol* as well as the thinking that has emerged through the making of this project. By realizing a network of solar-powered servers that collectively serve a web platform from wherever there is the most sunshine, we've explored a form of automation that does not rely on AI, but on a kind of natural intelligence that emerges from planetary dynamics. Through this work we have also articulated six prompts for a more energy-centered design: *Make Energy Data Public, Design Energy Responsive Systems, Account for Where Computational Work Happens, Acknowledge Intermittency, Use Planetary Limits as Logic* and *Question Resolution*. These are tentative and we share them as provocations for further experimentation and dialogue on how to design with intermittency, what follow-the-sun computing might look like, and how the energy transition offers rich opportunities to rethink and redesign our many varied relationships with computation.

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