Low Power Web: Legacy Design and the Path to Sustainable Net Futures

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CHI 2020 Extended Abstracts, April 25–30, 2020, Honolulu, HI, USA.

ISBN 978-1-4503-6819-3/20/04...$15.00.

DOI: https://doi.org/10.1145/3334480.3381829

Abstract
HCI is complicit in the climate crisis, as the systems and services that we design engender unsustainable energy use and waste. HCI has equal potential to find solutions for environmental challenges and script, by design, the behavioral changes needed for sustainable net futures. We explore this dichotomy through the lens of data transmission, examining the energy consumption and environmental impact of web communications. This work begins with a critical revisiting of legacy web design that mines the past for actionable ideas towards sustainable net futures. We query how we can reduce our own net energy consumption, and plot a path to design our low-power website. In addition we speculate on a redesign of the background systems, outlining the practical steps we have taken towards solar, wind, gravity and micro-hydro low-power web hosting solutions.

Author Keywords
Sustainable Design, Low-Power Web, Green HCI, Renewable Energy, Web Design

CSS Concepts
•Human-centered computing~Human computer interaction (HCI)~Interaction paradigms~Web-based interaction•Social and professional topics~Professional topics~Computing industry~Sustainability

Walk the Walk

In the main text we outline a number of practical strategies in web design to reduce the environmental impact of our web presences. These easy to follow suggestions about making pages more efficient are based on established search engine optimization (SEO) practices. Yet as a design group within HCI, and active proponents of critical and design speculations, we also challenge the rhetoric of low-power, sustainable web communication, and ask how we might walk the walk with our own project communications.

In this side text we describe a series of actions and empowering initiatives, developing for and hosting on low-carbon renewable energy webservers. We invite our audience to walk with us on this path, as far as they feel comfortable, confronting the constraints and together redefining our relationships with internet services.

Motivations

The most recent reports on the state of the environment and progress, or lack thereof, in cutting carbon emissions suggest that without drastic change, a climatic cataclysm is inevitable [31; 58]. The socio-political, economic and environmental challenges of the present portend disaster for the future and dire projections of population growth, dwindling resources, rising temperatures and ocean levels, and extreme meteorological events that define the new normal will only worsen for future generations. Yet futures research is not limited to articulating, and therefore arguably perpetuating, the dystopia and fatalism encapsulated in the term Anthropocene [26]. One of the tenets of design for the future is re-examining our past and present as they set the stage upon which life will be acted out from now unto tomorrow. We must ask ourselves what we, as individuals, groups, societies, institutions, administrative bodies, and as a community of HCI and ICT researchers and practitioners more broadly, can do to divert the calamitous current trajectories - and if not avoid an entirely dystopian future, at the very least work towards decelerating climate change.

HCI shapes ICT, and our communities of research and practice are actively seeking solutions to the climate crisis, through development, education, and in particular information sharing and technology transfer to societies and citizens in developing economies who are feeling the effects of climate change sooner and more severely than the global North [43]. With our attention largely focused on the positive contributions of HCI [60], the greening of ICT [49] and work towards fostering energy sustainability [28], it is easy to overlook the fact that digital is inherently electronic: it consumes vast amounts of energy, the production and waste of which is the primary driver of climate change. It is tempting to think that the net good of our medium balances this out, something akin to "I'm not a vegan, but I cycle to work." However, this perspective is narrow, even misinformed, [4] and we need to pay attention to unequal global balances. Although expanding access to information is indeed empowering individuals and communities to fight against climate change, just under half of the world's population currently lives without Internet access [33]. Yes, available bandwidth for data transmission has increased astronomically around the world, allowing everyone faster, more complex sharing and use of data. However recent surveys suggest that nearly half of mobile internet users in emerging economies experience problems with connectivity, over a third limit their use because of data charges, and a third have difficulty even finding a place to charge their devices [53]. Commercial and marketing practices pushed consumer expectations in the global North from 1Gb of free storage in Gmail accounts to more than 15Gb, then to seemingly endless cloud storage potential. Yet up to 40% of mobile internet users in emerging economies rely on limited-service data plans, or free public Wi-Fi for their connectivity [55]. As such the perceived benefits of Internet and data connectivity are disproportionately distributed, even as over a million more people are coming online every day [35]. This is exacerbating another less visible problem, that increasing internet connectivity is driving power consumption in emerging economies faster than economic growth [50]. Thus predictions of global energy consumption based on economic activity could in fact be much lower than actual growth in energy

Green Hosting

The first step we can take towards sustainable web presence is switching to green hosting. Supporting internet providers that use only renewable energy is a straightforward contribution, requires no actual design changes to a website, and is something that every individual and organization should consider. Another option is to build pages on a free provider that uses renewable energy for its data centers [23].

There are many options for green hosting and the more demand for services that utilize 100% renewable energy, the more this sector will grow. We choose 1984 hosting in Iceland, whose location correlates with our own focus on island futures research. In addition to their use of green energy sources, they pay particular attention to privacy and security which we believe are aspects of sustainability that have yet to receive proper attention.

demand, putting into question global targets for carbon emissions.

Our community must exemplify best practices for energy use rather than enforcing overconsumption. We are well aware that the devices, systems and services that we create can engender, or script particular behaviors among users [59] and we should leverage this towards sustainable energy practices. Sustainability often seems like a macro issue, the contributing factors seem beyond our individual control, and those solutions that are available require sacrifices that governments, institutions and industries are not yet willing to make. Yet, as with every light bulb left switched on, and every single-use plastic bottle discarded, everything we do on a micro scale contributes to a much larger problem. We examine here the most micro of elements, the bits and bytes of data that underpin ICT, probing how our use and abuse of them contribute to climate change.

Data and energy

For years the discourse concerning the impacts of ICT and climate change has simmered [41], and recently boiled over into more alarming, perhaps alarmist, calculations of the energy requirements of ICT. Already in 2015, global data centres consumed more electricity than the UK [6] and some warn that ICT's current 2% share of world electricity consumption will rise to as much as 20% in the next decades [34]. Central to such extreme projections of runaway energy use by ICT is the rapid growth of the Internet and exponential increases in storage and flow of data over the Web. This issue has been under investigation since the 1980s, using various approaches. Some researchers try to account for the energy demands of Internet infrastructures, the servers, switches, routers, communication towers and equipment upon which the internet functions [29]. Others focus on the data centers that background internet traffic [42] or specific aspects of data use [54] and some attempt to include energy expenditures of end user devices and [8] even the energy expenditure associated with the production of all of these devices [51]. The conclusions and predictions derived from several decades of research vary widely, and only scratch the surface of the challenges and complexity of calculating current and future energy impacts of ICT [2; 46].

Regardless of the explosion in data use, the share of world energy production consumed by ICT over the previous decades has in fact remained relatively stable [51]. Due to efficiency gains in server architectures, centralized and optimized data service management, and the stripping down to essential components of the machines actually running the internet [18], power consumption associated with data is increasing disproportionately. The 300% projected rise in data use by 2030 is predicted to claim only a further 1% of global energy [44]. As low-power mobile devices account for an ever-increasing share of data consumption worldwide, some projections even foresee a relative decline in ICT carbon emissions [40].

This is not to say that everything is fine, however. Energy waste in our technological infrastructures is rife. Recent audits of legacy server farms found up to 25% of so-called zombie servers, machines which are powered on and connected to the internet but rarely if ever serving content [36]. As for those machines that are in constant use, the percentage of potential processing power being utilized for server functionality is commonly as low as 6-17% [38]. This means that a

Web Design
As per the suggestions in the main text, our web pages should be designed with a simplicity of code and a balanced and aesthetically pleasing design. Pages can be hand-coded and require no external server connectivity, or can be built using a CMS. JavaScript libraries can be reduced to their necessary functionality and self-hosted, or developers can take advantage of caching and link to the common libraries. Most important: no cookies, no tracking pixels, no Google analytics, no auto-play videos, and try a page budget of >200Kb per page.

large proportion of energy consumption by each server machine is simply being wasted, as is another estimated 10-12% of data center power due to inefficient power distribution systems [37].

In addition to this, cooling systems consume as much as 30-40% of a data center's electricity use [21], an issue that data industries are actively addressing, if not out of concern for the environment, then for bottom-line cost savings [3; 11; 17]. Data service providers have begun promoting their Power Usage Effectiveness (PUE), calculating the amount of energy used by a data center and how much of that energy is actually used by the servers' processing data [62] as a measure of their efficiency and "green" credentials. Yet PUE only accounts for overall efficiency of a data center rather than the efficiency of individual machines or their combined performance as communication systems [27].

The all-consuming Internet
Similar to electrical power in a wall socket, availability and abstracted ease of use has led HCI practitioners, designers and subsequently consumers to expect the data-driven Internet to always-on, immediately available, and we utilize all manner of web communications without much thought of material resources and consequences. However, pinning down and making visible the actual amount of energy consumed by data is a treacherous undertaking [5] and the variety of methods proposed to identify the actual Kilowatt Hour (kWh) required by one GB of internet data transfer compound the challenge. Estimates vary widely, from .02 kWh per GB averaged across wired and wireless transmission systems [1] to 5 kWh per GB [10] or more. In addition, the energy utilized by email is significantly less than that consumed by video [51]. For reference 1 kWh is roughly the equivalent of one cycle of a washing machine, powering a refrigerator for several hours, or watching 100 minutes of video online. Putting this into perspective, 840 million people worldwide still have no access to electricity [16] and 50 million people in Europe cannot afford energy costs [56]. Such energy poverty constrains the capabilities of individuals and groups to achieve basic needs and increases inequalities [12; 45], and while reducing the energy consumption of technological artifacts is being addressed on the margins of HCI [13], we believe it should be mainstream and explicit in our community's social and political agenda [14].

Quantifying the energy consumed by data use is as yet an inexact science, but it is essential to focus attention on the servers, routers, modems, transmission towers, and end user devices that consume energy, and how each page of the Internet has a potentially measureable impact. One interesting project, websitecarbon.com, provides an online calculator to assess any website's associated carbon emissions, based on 1.8KwH/GB, and is a good starting point to examine our web presences. Regardless of the accuracy of the calculations it illustrates that not all sites are equal in their consumption. The bottom line is that every byte we store and serve contributes to the growing problem of energy consumption, and every byte we can reduce will reduce our carbon emissions.

Of course, to design for this we don't need to speculate on a world with less data, as this was our reality not so long ago. In imagining more responsible future practices we would do well to examine previous, more sustainable times [57] and revisit the design

Pi Server

Following inspiration from our colleagues at Low-Tech Magazine, we have been developing on a Raspberry Pi-based low-power server. Such micro-controller web hosts use minimal power and can be connected to the internet via Ethernet link.

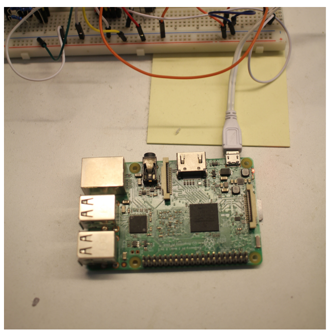

Figure 1: Raspberry Pi server

Tech Support

All of the public access nodes associated with our institute's IP are occupied by other projects. This constrains our taking full control of web hosting. However if your infrastructures allow for it, you can be on the path to independent web hosting…

considerations and techniques used to deliver and navigate early low-bandwidth internet. We should question the amount of data and energy that the things we design currently consume, and that force others to consume in order to engage with us. Current levels of waste are unnecessary, inequitable and out of step with our progressive rhetoric as a community.

A case in point is provided by a media forensic analysis we performed on ACM's own website in December 2019. The landing page makes over 100 server requests and loads up to 12 MB of data, including 3 MB worth of preloaded images and several more MB of JavaScripts. The introductory video, hosted at YouTube, is 34 MB. ACM itself was setting 14 cookies through the homepage, only 6 of which are tied to acm.org[1]. Of the total cookies set, 27 were from external sources such as Reddit, Twitter, Facebook, Google, Quora, YouTube and others. Although these cookies represent only a handful of bytes, they send information piggybacked on subsequent HTTP requests and activate more than a dozen external servers. Some of these cookies are essential to site functions, but many are extraneous and serve little obvious purpose towards the actual communication of ACM.

ACM has held at least seven symposia on Computing and Development, and purports to support a global community and membership in emerging economies through its special interest groups [48; 52]. As previously noted, unlimited broadband availability is not universal, and a large percentage of potential visitors in developing countries are on pre-paid data plans, hence clearly conscious of their data usage and the costs incurred. The ACM site exhibits a neo-colonialist procedural rhetoric: through its form and function it suggests that visitors in the developing world should consume data at Western, Northern levels. For people inquiring about the ACM community and hoping to access basic site information, the homepage represents not only an excessive drain on their energy resources, but a potential barrier to participation due to its data-heavy design.

The path to data redemption

From a design perspective, several main constraints arise in any effort towards designing low-power websites, for example the aesthetic value we wish to infuse in our web presences and the functional requirements of delivering content. In addition we must contend with the expectations of our audiences, which have been trained to great extent on always on, fast-loading, high definition, full screen everything, and we need to balance the communicative potentials of multimedia content and data load. This issue is gaining attention in some circles, as an offshoot of broader investigations into designing for sustainability [32; 47]. In terms of web design, four paradigms of sustainability have been suggested: content strategy, performance optimization, design and user experience (UX), and green hosting [19].

The ultimate goal in this work is to reduce page size to a minimum while retaining a certain standard of acceptable quality for the designer, client and audience

[1] While the site states that "ACM only uses analytical cookies and does not use any user-specific targeting cookies." https://www.acm.org/privacy-policy the Encrypted Facebook ID and Browser ID 'fr' and DoubleClick 'IDE' cookies were being set at the time of writing, both of which are targeted advertising trackers.

Solar Power

If you are in possession of, or have access to funds for solar panels, the Pi server can be powered entirely by the sun. Place the panel(s) in the sunniest part of your institute's outdoor space, or secured to a frame, preferably built from recycled materials. One or two panels will provide more than enough solar energy to run the Pi server during daytime hours, even on partly cloudy days. When solar energy is unavailable, the Pi will simply shut down and the site will of course go offline.

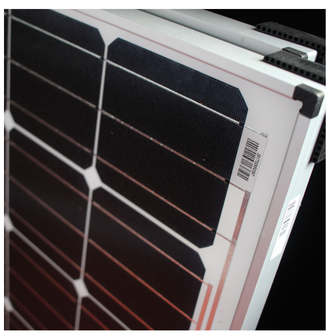

Figure 2: Solar panels

– a practice that already formed the basis of web page optimization before broadband. While this has been phrased more recently in terms of energy conservation, the four paradigms largely involve legacy practices initially aimed at faster page loading times, search engine optimization (SEO) [39; 61], responsive/adaptive design across devices [20] and creating engaging mobile user experiences (UX). We consolidate our reflections here into optimizing three areas - images, video and code - weighing these against aesthetics, functional requirements, and user experience of site visitors.

Image Optimization

As text information regardless of its length is almost always the least data-heavy portion of a web page, the most impactful data transfer reductions result from shrinking the multimedia elements being presented, their pixel dimensions and compression. Balancing text and images on a page is a hallmark of good page design, a legacy from print media in which use of images was mediated by the cost of ink and paper. With the switch to digital media, publishing tends towards image-heavy layouts, and the spread of broadband has driven a corresponding increase in web page size in the last decades [30]. Yet the initial enthusiasm for large images is being tempered with the growth of mobile-first concepts [20] and attention to fast-loading pages [22] driven by the exigencies of mobile data transfer and the[22] driven by the exigencies of mobile data transfer and short attention spans of visitors [9]. In efforts to reduce overall page size and load times, an emerging technique is defining a page budget, determining the maximum acceptable page data size, measured in KB, with subsequent decisions in design and layout revolving around that. However for publishers using content management systems (CMS), design and layout decisions are fixed a priori by template developers, who may or may not be attentive to data transfer size and energy conservation.

The next challenge is image compression and achieving an acceptable visual clarity while reducing media data, which is accomplished easily with both commercial and free and open source tools [15]. How small an image can be compressed is largely dependent on its dimensions, but also image content, file type, color depth and compression codec [24]. Attention to the differences between formats, their pros or cons vis-à-vis image content, and the meticulous testing of compression settings for each particular image, once an essential aspect of web design, has given way to the use of generic, automatically applied presets. An informed human operator can almost always squeeze out more data through trial and error. If attempts to reduce an image data size do not produce acceptable visual results, it may be necessary to revisit image content itself or devise another design trajectory for the site. Images with greater detail by default require more data to retain acceptable visual quality, whereas solid blocks of color can be compressed smaller. Scalable Vector Graphics (SVG) can replace raster-image logos and retain crisp clarity at any display size, but of course an entirely vector-based graphic design leans towards an aesthetic that may or may not be acceptable or communicate as desired. Optimization continues on the meta-level and removing EXIF data from photographic images can further reduce data size, deleting information that is often unnecessary for, or even inaccessible to viewers. This can be done in many popular image editing programs, and savings per image are not inconsequential: camera data, timestamp, geo-

Wind Energy

To bridge this gap in solar energy availability, a small wind turbine can be added to the system. This can potentially keep the site online during windy nights and cloudy days, and need not be of massive dimensions or substantial investment. Small wind energy systems, for example those commonly installed on sailing vessels, can provide sufficient power for the Raspberry Pi server.

Figure 3: Turbine design

location, thumbnails and other embedded metadata can weigh up to 64KB per image.

Image Presentation

The optimization of images is only part of the picture, and further data savings can be made by properly coding them into web pages. Frequently larger images are loaded and then scaled smaller when displayed in the browser. This is often a matter of convenience as automated workflows and CMS responsive layout settings frequently employ larger size than is absolutely necessary. On the ACM landing page, for example, article stub images are displayed at 326 x 184 pixels, while the actual images being downloaded are 764 × 430. Even when zooming the browser window up to 175%, the images are only displaying at 42% of their data size, in effect wasting more than half of the data transfer. Where the detail of a large size image is necessary to provide more information, one solution is to load a smaller compressed image and allow a user to choose to load the larger image via a link. Similarly, image preloading strategies as on the ACM page contribute to significant data waste: 36 images are loaded for a total of 7MB, but the home page only displays 17 of these images. If a visitor does not scroll down the page to view every stub, or visit every other page for which the images are required, roughly half of the image data loading is pointless. While preloading images does speed up subsequent page loads, the design of the site presumes that every visitor will read every page - which a perusal of site statistics would likely prove misguided.

Video waste management

Perhaps the most egregious impact on the quickening of internet energy consumption has been the rapid growth in video on demand (VOD) and more recently, movine-image backgrounds. Not only has the number of video streams multiplied, but so too has the broadcast of dead space. Moving image content is careening away from carefully curated cinematic representation in which scenes and entire storylines might be cut from a work to meet a broadcast time limitation. What emerges in its place is Instagram, Facebook and TikTok video that eschews editing for "authenticity" and disregards limitations of time or bandwidth. The mindless consumption of the moving image is becoming de rigueur as suggested video channels push content that may or may not even interest the viewer. Any suggestion of limiting certain kinds of video risks entering into war over whose content is truly worthy of the energy expenditure of its broadcast, and will likely be met with 'OK, Boomer' from younger viewers[2]. Yet in service of a sustainable future web, we would all do well to question if our video consumption is relevant, necessary or justified.

In practical terms, mitigating the impact of those videos that we do post online is akin to optimizing images, reducing frame size and tightening compression. Videographers are often loath to do the former, while the latter is commonly effected using generic export settings of popular formats. These produce larger files than do superior open source compression tools and codecs [7], although it is important to note that computing power and time required to generate the most efficient web video can

[2] Arguably it was Generation X who seized control of independent filmmaking and defined videography, creating the market for inexpensive video cameras and prosumer editing software.

Backup Power
We find it novel, the idea that a website be available only when local solar or wind power can support it. As such, the offline site could comment on visitors' on-demand expectations. However, a backup battery offers 24/7 availability, and in keeping with our location, we would add a 12v 80AHr marine battery, although Lithium-ion storage would also do. This should be sufficient to keep the website online for up to a week of sunless days. However given our location on the sunny island of Madeira, this situation is highly unlikely.

Figure 4: Marine Battery

consume significantly more energy [25]. Making more sustainable video transmissions requires not only close attention to video compression, but also some rethinking of video production processes. This is reminiscent of legacy practices, as early digital filmmakers made conscious choices in mise en scene and camera technique to directly compensate for limitations of the medium. One example of this is interlacing, the precursor to progressive scan video, which introduced visual noise particularly in scenes with filigreed detail and movement. Videographers adjusted their shooting to reduce that noise: a talking head presenter would never be allowed wear a striped shirt, and filming of side to side motion was minimized in favor of movement towards or away from the camera. Contemporary videographers must be similarly attentive when producing video that is destined for heavy compression.

Technology and technique

Video compression most commonly relies on software analyzing groups of pictures in sequence (GOPs), identifying similar blocks of pixels each frame over time, and combining them to reduce the amount of data. In playback the frames are re-built based on the information in the GOP and integrity is restored to each individual frame. With greater detail and change across a series of frames, compression can reduce the data stream while maintaining visual quality. Armed with this basic technical knowledge of the video codec, videographers can amend their video capture with a mind to its eventual compression. A scene with many objects in motion is going to compress poorly, whereas isolated motion on an otherwise placid field can be heavily compressed while retaining detail of the moving object. A scene with a clear and uncomplicated background will compress nicely, as will a busy, stationary background but only if the camera is completely still. Even miniscule movement of an operator handholding their camera can increases data in the GOPs exponentially. Additionally, using footage taken either by the same camera using different settings, or incorporating footage from different cameras with completely different profiles, or video footage previously compressed into a different codec all introduce complications in video compression. As such, employing higher production values, proper planning and alignment of video capture sources can go a long way to reducing the eventual data size of a web video.

Reduction in data size of video size can be taken even further with the audio compression. Clear, high fidelity audio recording will compress into a smaller file to accompany the video than will noisy audio signals. This might require the investment in a quality camera microphone or a separate recording device whose tracks are synched in postproduction. Stereophonic effects can also be eliminated, if they do not actually contribute to the communication. Exporting mono audio reduces the audio part of a video file up to 50%, and as many web videos are played on laptops and mobile phones with poor audio output, stereo audio may be adding data to a stream unnecessarily. The majority of talking head videos will communicate just as well in mono.

Further reductions

As with images, further reductions can be gained in the video presentation in a web page. A video can be offered in different sizes and quality, even signaling to potential viewers the greater environmental impact of choosing a larger download. Rather than embedding a

Gravity Battery
Taking the project into the realm of working design speculation, we propose a system without the marine or Lithium-ion battery. This would incorporate the solar and wind energy collected by our initial setup, and in addition would utilize a gravity battery for backup power. This would in turn operate a smart switch to controls operation of a closed circuit 250Litre micro hydro power plant. During peak solar and wind energy, excess power not being used by the webserver would be used to charge the gravity and hydro components.

Figure 5: Gravity Battery

video player code block, links can be provided directly to the video hosting site to avoid unnecessary server activity. Where players are embedded, the autoplay function can be turned off by default, to limit playing even part of a video that a viewer does not actually want or need to see.

A last but not insignificant means to reduce energy consumption of video is simply not to offer video at all. Do we really need to see the standard content of institutional videos, the talking heads, exterior shots of university departments and interior views of labs? The resurgence in popularity of audio via podcasting can be leveraged to significant advantage in terms of sustainability. A mono audio substitution for a video can in many cases communicate meaning just as well, relying more on the oral storytelling abilities of the presenter than on visual cues. The rise of podcasting is proof of the absolute engagement of an audio stream; the lack of visual cues even enhances the powers of focus and imagination. Indeed, podcasts give more control to an audience than video, as one can go about other activities while enjoying an audio stream, free from the visual dependency of screen based media. OK, Boomer!

Streamlining code

Again using the ACM website as an example, the site loads 19 JavaScript files that weigh 2.8 MB. Some of this code is clearly setting up essential functionality for the site's UX and UI, such as cookie consent, window and event handling, but it also includes significant chunks of code for Facebook, YouTube, Twitter and Quora among others. These are largely interconnectivity conveniences that for many visitors are extraneous. A visitor who does not use social media, or is disinterested in a 34 MB promotional video, gains nothing from this code towards their interaction with ACM. A browser with strict security settings rejects up to a dozen of the page's back-end requests and tracking setup activities. This reiterates how the design and implementation of a site can force code and data use on visitors, regardless of whether it is needed or wanted, in the process wasting energy from the servers and the end-user's access device as well as potentially incurring unnecessary data charges. In the interest of sustainability, we must ask ourselves: Can we make engaging web experiences without a ton of JavaScript code? Can we strip out all of the extra, often unrequested functionality and still present a coherent, informative and inviting web presence? And in cases that really do require fancy code, can it be optimized to provide the functionality we want without triggering dozens of requests from distant servers? Or is the use of caching via scripts drawn from a content delivery network (CDN) always the best option?

These questions extend to the serving of static pages versus dynamic ones. A static page is created once and delivered complete from the webserver. A dynamic page in contrast requires multiple server actions to build the content and deliver it to the viewer. Dynamic pages are of course the backbone of the contemporary web experience, facilitating interactivity with site visitors and ease-of-use for content creators. However for web pages that do not require commenting or live updates, static HTML pages are equally communicative. Designing a site that is predominantly static pages and leaving multi-server requests to those pages that absolutely require them is a potential strategy that need not interfere with the aesthetics of a site, and can even increase its engagement by reducing load times.

Micro-Hydro Plant

When solar and wind power are waning, the smart switch will initiate the gravity battery's several minutes of backup power. The micro hydro plant is then engaged, and water from a primary tank falls into a secondary tank, passing through a miniature Pelton wheel turbine. Such a system could provide up to 8 hours of power to the Pi server, until daybreak or when the wind increases again. Water in the secondary tank is pumped to the primary reservoir to ready the system for the next dark and windless period.

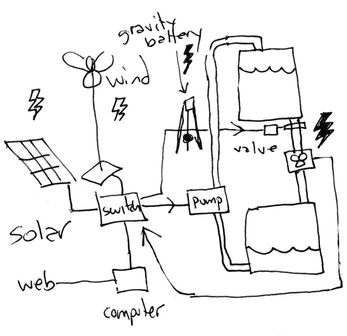

Figure 6: Micro-hydro plant
© max willis

Dynamic content such as maps also triggers various external server requests. While an interactive map might seem like an integral part of a website (embedding code for a map viewer that every visitor must load), simply linking to a Google map or one of the alternatives such as OCM provides the same functionality. Rather than removing the convenience and utility of mapping services altogether, the choice is passed to the user as to whether they need this functionality or not. When embedding maps in a webpage is absolutely necessary, setting the default presentation to use standard map layers can save data transfer, as satellite data images have a larger data size than vectors or PNG map layers.

Other strategies to consider are consolidating CSS and JavaScript files, hosting the files on the same server as the content rather than linking to external resources and stripping down JavaScript libraries to only those aspects that are being utilized by the site, and rethinking the use of cookies. These can all reduce server requests and data load, and limit the energy consumption of a website.

Conclusion

HCI is complicit in the climate crisis. In this paper we have drawn attention to the energy consequences of the devices, systems and services that we as researchers and practitioners create, and how these perpetuate an unsustainable and wasteful Internet ecosystem. We provide a breakdown of several pathways to making our web use more sustainable, by reducing the amount of data and server activity required. Our basic message is that as designers and developers we need better understanding of the technology and greater control of our workflows in order to build more sustainable websites. The solutions suggested here focus on balancing design and communication, seeking greater understanding of the technologies involved, and taking control of and even writing more of our own code. Each of these require some level of technical knowledge, but if we are asking what we can do to conserve energy, and how we can build things that consume less, then training up can be part of our conservation practice. In the sidebars of the paper, meanwhile, we have presented a step-by-step documentation of our own efforts to "walk the walk", not just talk the talk of sustainable web development. Not everyone has access to the material resources and the availability of engineers to experiment with and implement low power web services as we have done. Yet much of what we have already implemented, and the design speculation for the ultimate renewable energy server system, is based on freely available online resources. It's not rocket science - all that is needed is some motivation, time, and an investment in human energy to start out on a path to energy sustainability that will benefit all of us.

Acknowledgements

We gratefully acknowledge support from LARSyS, the REDEMA project, and our colleagues Victor Azevedo, Vitor Aguiar, and Harry Vasanth. This project has received funding from LARSyS - FCT Pluriannual funding 2020-2023 and the Portuguese Foundation of Science and Technology (FCT) Project Ref PTDC/ART-DAQ/31691/2017

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