User Tolerance as a Factor in Sustainable Website Design

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The internet is responsible for 3.7% of the world's carbon emissions, a number that is expected to increase. Websites alone are a notable aspect of the internet experience, but there are design choices that web developers can make to lower the carbon footprint of their websites. However, such changes often present a tradeoff between a lower carbon footprint and traditional quality of experience (QoE) metrics. In this work, we explore the type of QoE drop that users will tolerate to lower their carbon footprint through a case study. We built a browser extension to make energy efficient changes to a commonly used website, and we conducted user surveys. We found that users are more tolerant of QoE drops when they know the effect on carbon emissions; in fact, they more often preferred a version with lower QoE. We also asked users to customize the website according to their preferred tradeoff of QoE and emissions and we present insight into the variety of changes that users tolerated.

CCS Concepts: • **Social and professional topics** → **Sustainability**; • **Information systems** → *Web interfaces*; • **Human-centered computing** → *User studies.*

Additional Key Words and Phrases: Web pages, Quality of Experience, Sustainability, Carbon Emissions

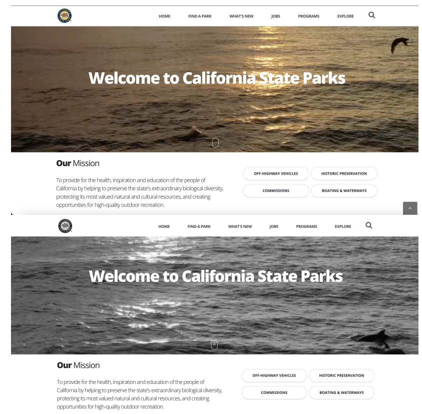

Fig. 1. Original version of CA state parks page (above) and a version with 50% carbon emissions (below)

1 INTRODUCTION

The carbon footprint associated with web browsing is steadily increasing as the internet serves more data. Each process associated with serving data - powering servers at a data center, transferring data over the network, and displaying data on the user's device - uses electricity [7], 60% of which comes from carbon intensive sources [4, 5]. This electricity usage results in the internet being responsible for 3.7% of total greenhouse gas (GHG) emissions [15].

This number is expected to increase to 14% by 2030, due to increasing page weight, or amount of data on a webpage, as well as more computation at the server, e.g., serving AI-based results [4]. In this work, we focus on page weight because, following the Sustainable Web Design's method of estimating digital emissions, the number of bytes served impacts the carbon emissions of each step of the data serving process [7]. That is, a page with high weight means that more bytes must be stored (typically in several locations) at data centers, which 1) contributes to a rise of data center storage and infrastructure, driving up embodied carbon emissions, and 2) requires electricity to power, increasing operational emissions. It also means that more bytes must be transferred across the network and rendered at the end user's device, further increasing the electricity demand. Page weight has increased dramatically in recent years - 221% and 594% for desktop and mobile devices respectively between 2012 and 2022 [12] - largely due to the rise of data-intensive image sharing and video-based applications [14].

One approach to curbing this trend is for web designers to make changes to their sites that effectively lower the amount of data, or reduce bloat. To that end, the Sustainable Web Design foundation and WholeGrain Digital have published guidelines outlining the many choices web designers can make to reduce the carbon impact of their designs [6, 9]. These include, for example, lowering the number of images, stopping auto-play on video, using system fonts only in favor of those that need to be loaded, and using "dark mode". Another approach is for data centers to rely more heavily on renewable energy sources. While many data centers are shifting more to renewables [10, 18], they are still far from being able to fully cover the increasing energy demand of data centers [16]. These two approaches can even be combined such that sites display their visual elements differently based on the grid intensity, or the amount of GHGs produced per unit of electricity. For example, a page might show with a several high-resolution images when the grid intensity is low but scale back to smaller images or vector graphics when the grid intensity is high. Alternatively, the website might provide multiple versions so that users can choose which they prefer. An example can be seen in Figure 1, where the version on top is the original, and the version on the bottom emits 50% less carbon because the video's auto-play is halted and images are blurred and converted to grayscale.

In practice, these carbon aware changes are deployed on few sites, often related to climate action, such as Branch magazine [1] and WholeGrain Digital [3], though the "Grid aware websites" project aims to make these changes easier to implement [13]. Many of the proposed changes conflict with tradition metrics of quality of experience (QoE) on a website, in particular visual appeal. To maximize visual appeal and engagement, designers are encouraged to use high quality images, videos, and high-color [17], directly conflicting with energy efficient recommendations. The "Grid aware websites" project acknowledges this tradeoff and describes the challenge facing front end developers to get buy-in for implementing carbon-aware changes, stating "Sometimes they *may* be able to

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implement low-impact web design if they can secure stakeholder buy-in. *Sometimes. Maybe*".

Despite the difficulty of navigating this tradeoff between QoE and carbon footprint, there is promise that user preferences, or their personal QoE, might change if they knew the difference in emissions. Hoßfeld's work shows the existence of "green users," who tolerate a lower QoE, according to existing metrics, for the benefit of lowering their carbon footprint [11], in the context of bitrate adaption for video streaming. Applied to websites, similar results could present an opportunity to allow for a controlled degradation of QoE and an increase in ability to use energy efficient website design. For example, if we knew that users would tolerate a lower resolution video for the sake of a lower carbon footprint, we could reduce the amount of data associated with the video and thus the carbon emissions associated with the site. That is, rather than treating QoE as a metric to be solely maximized, we could treat QoE as a tunable parameter and find the optimal point in the QoE – carbon tradeoff.

To achieve an optimal point in the QoE – carbon tradeoff, we need an in-depth understanding of user tolerance to QoE drops in websites for the sake of a lower carbon footprint. In this work, we take a step towards a better understanding using a case study of a commonly used academic website. We ask two questions: 1) How does a user's preferred version of a website change if they know information about the carbon emissions of each version? 2) Which specific changes among the recommendations do they tolerate best, with knowledge of carbon emissions of each change?

In our case study, we surveyed users of the website with various relationships to it. To answer question 1, we asked users to choose between different website versions, first without and then with knowledge of carbon emission differences. To answer question 2, we then asked users to customize the website, seeing carbon updates in real time.

The key contributions of this work are to present the results of our case study, analyze the extent to which users tolerated QoE drops and the types of drops that are best tolerated, and open discussions about the viability of QoE as a tunable parameter in web design for "green users".

2 METHODOLOGY

2.1 Website

Our case study was conducted with a commonly used academic website that functions as an advertisement for prospective students, a news source for current students, staff, and alumni, and as a landing page for more detailed information such as majors, courses, and dining hall information.

The website includes a large, auto-playing video, and once the user scrolls down, there are news blurbs, graphics displaying college statistics and awards, and links to department information and other college activities. The Website Carbon Calculator [2], which uses Sustainable Web Design's emissions modeling [7], gave it an F for carbon emissions, with worse emissions than 74% of websites globally. Screenshots of the website are shown in Figure 2.

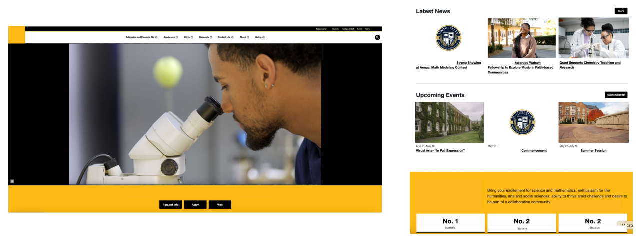

Fig. 2. Video and news/statistics components of website

2.2 Participants

In choosing study participants, we aimed for a group of individuals who had varying interactions with the website. Our three groups were current students, faculty/staff, and alumni. We advertised our study through word of mouth and social media, and we interviewed 7 students, 6 alumni, and 6 faculty/staff, resulting in 19 interviews overall. Though prospective students are an important target, their status as minors limited our ability to interview them. Chosen students, staff, and alumni had a diverse range of majors/specialties. Alumni all graduated within the last 10 years.

2.3 Website Alterations

We developed a list of potential changes to the website based on Whole Grain Digital's article, "20 ways to make your website more energy efficient". The suggestions that involve aesthetic changes to a website include: "reduce images", which involves removing them completely, making the image size smaller, or using vector graphics instead, "reduce video", which involves removing autoplay, shortening videos, and lowering the size, and "choose fonts carefully," suggesting that developers choose system fonts rather than importing fonts.

To implement image reduction, we **blur images** (reducing the amount of data stored by allowing for more compression), **transform images to grayscale** (cutting the number of channels from 3 to 1), or **delete images** entirely. The options to reduce the footprint of videos are **halting auto-play** (assuming that the user does not press play), **converting the video to grayscale** (similarly cutting the channels in each frame by a factor of 3), or **deleting videos**. Careful selection of fonts is most effective when no font file must be imported: Arial is pre-installed on most OSs, including Mac and Windows, making it an ideal font candidate, so we include **changing the font to Arial** as an option. These website alterations are primarily concerned with reducing the total amount of data transferred from the server to the end-user, which in turn reduces its carbon footprint in accordance with the Sustainable Web Design estimation framework [7]. A website without certain elements would ideally be redesigned such that their absence wouldn't be as noticeable. Due to the limits of a Chrome extension, we simply removed/altered elements, which is less aesthetically pleasing.

2.4 Measurements

To estimate the emissions of each change, we used Sustainable Web Design's CO2.js library. Given the total size of data transferred during a web request, as well as the carbon intensity of the server, network, and end-user, CO2.js will estimate the carbon footprint of a website. CO2.js incorporates the Sustainable Web Design (SWD) model, which assumes that a page's weight is proportional to its emissions. SWD acknowledges that this assumption is controversial, given the "robust discussion in the web sustainability community on the suitability of using data transfer as a metric". Despite debate, data transferred is widely used, simple to understand, maintains consistency across past iterations of SWD models, and is a "proxy metric" to account for bloatware [8]. Thus, we felt comfortable in using CO2.js to estimate our site's carbon emissions. Due to uncertainty in the exact network route a web request takes for our site, we used CO2.js's built-in "USA" grid intensity as our final input.

To complete our CO2.js carbon footprint estimations, we measured the amount of data transferred in bytes, given various changes to the site. To do so, we utilized the Chrome Developers tool, which monitors the amount of data transferred per web request and allows for the blocking of specific kinds of web requests. While the Chrome Developers tool can estimate page weight when videos and images are disabled, it was not possible to use this tool to determine page weight when images/videos are grayscaled or blurred. We measured the average amount of data transferred in 4 cases: control (website as is), disabled .mp4 files, disabled .mp4 and .jpg files, and disabled autoplay. For each experiment, we found the average amount of data transferred across 5 trials, quitting & restarting the browser between each run to clear the cache.

Next, we measured the size of altered images and videos after they've been blurred or converted to grayscale. Note that we changed the images and videos on the user side and then measured, but the website would have to provide the altered image or video to actually change the amount of data transferred. For our measurements, we used the Python libraries requests and BeautifulSoup to scrape images/videos from the site before performing the same blurring and grayscale alterations that would be later implemented in the extension. For each alteration, we compared the total size of the images or videos before and after, and used that data to estimate the amount of data that would be transferred theoretically if the website implemented each distinct change. Finally, we noted the size of the site's font file, under the assumption that a change to Arial would halt its import. Table 1 shows the measured and/or estimated size of the site, plus its corresponding emissions from CO2.js, for each individual alteration.

Alteration	Website Size (MB)	Emissions (gCO2e)
Control	77.02	27.89
Delete Video	5.7	2.06
Delete Images	74.02	26.80
Disable Autoplay	39.26	14.21
Blur Images	75	27.145
Gray Images	75.38	27.289
Gray Video	49.3	17.85
Font to Arial	76.9	27.838

Table 1. Size and Emissions from Site Alterations

2.5 Implementation

Both Part 1 and Part 2 were implemented through Chrome Extensions and developed and deployed locally. They were designed in JavaScript, CSS, and HTML, and deployed through Google Chrome. In Part 1, alterations are implemented before/at the site's load-time. In Part 2, the site implements visual alterations in response to button clicks. The extensions interact with the site's HTML and CSS to delete videos, images, font files and disable autoplay. Blurred images are constructed on an HTML Canvas element and re-inserted, replacing the site's previous images. To convert images and videos to grayscale, the extensions inject CSS into the site's HTML that overrides any previous formatting/filter.

2.6 Interview Protocol

We interviewed the participants by showing them the website in person or on Zoom. During the interview, they filled out an online form and controlled the laptop to make changes. This study was given IRB exemption (institution redacted for anonymity).

Users knew that the study was about the design of the website but were not told that the study involved sustainability. Interviews were divided into two parts. In part 1, we focused on the how a user's preferred version of a website changes depending on whether they knew information about the carbon emissions of each version. Part 2 focused on which specific changes among the Wholegrain Digital recommendations they tolerated best, with knowledge of the carbon emissions of each change.

2.6.1 Part 1. We first made changes to the website such that we had three distinct versions. Version 1 was the original and thus had a 0% decrease in emissions, while Version 3 implemented the most extreme changes, removing the images and video, and had 96% decrease in emissions. Version 2 presented a middle option, halting auto-play on the video and blurring the images, resulting in a 50% decrease in emissions. Version 3 is shown in Fig 3 (Version 2 and the video are omitted due to lack of clarity in seeing video halting and blurring).

For each interview, we first asked the participant to toggle between the versions and directed them to the form, which asked them to describe their impressions of each version in 3-10 words as well as which version they preferred to use. Next, we told the participant about the carbon emissions number of each version. The participant was then asked to again answer which version they preferred to use, as well as the factors that impacted their decision. The form poses questions about their interest in a similar tool that offers different versions of a website, and if so, what kinds of websites they could imagine such a tool being useful.

2.6.2 Part 2. Next, we directed the participant to the original website with a customization panel built into the top bar. The panel allowed them to make each of the possible alterations, such as "remove images", "stop autoplay", etc, which updated the page in real time and showed them the percentage decrease in carbon emissions based on the change, as shown in Figure 4 (website name redacted).

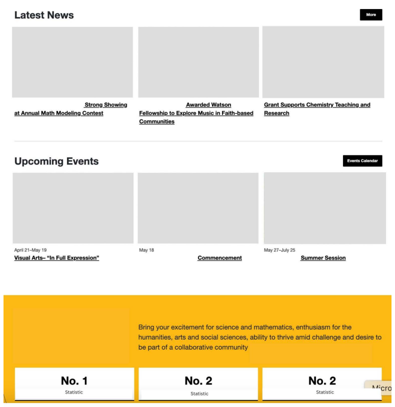

Fig. 3. News/statistics component of Version 3

They were given time to try the changes and decide on their preferred customization of the page and were then asked about their satisfaction level with the usability and aesthetics of their version. Finally, each participant was asked whether they could see carbon emissions being an important factor in which websites they choose to use and whether they believe climate change is a pressing issue.

3 RESULTS

3.1 Part 1

In Figure 5, we can see the results of part 1, showing which version of the website participants preferred, before and after knowing information about carbon emissions. We can see that before knowing emissions information, version 1, the original website, was considered most preferable (63.2%), followed by version 2 (31.6%), with only one participant preferring version 3 (5.3%). After each version's carbon-footprint was revealed, version 2 showed the most drastic change in desirability. Version 2 was considered most preferable (78.9%), followed by version 3 (15.8%), with only one participant selecting version 1 (5.3%).

These results can be broken down by relation to the website, as shown in Figure 6. From the breakdown, we can see the importance of surveying a wide variety of groups to understand the QoE-carbon footprint tradeoff. For example, students started out with the most favorable view of the website as is, followed by alumni, and then faculty/staff. The descriptive answers can help us understand the differences in initial preference. Students generally found version 1 "engaging", "lively", and "vibrant", while faculty/staff tended to use more words like "flashy", "busy", and "loud", while alumni had the greatest mix, including both "interesting" and "overwhelming". Students had the greatest rate of changing their answers after learning about emissions information (71.4%) compared to alumni (66.6%) or faculty/staff (50%), but we note that faculty/staff still ended up preferring lower carbon versions because they also started out with that preference. Given these results, it might seem that version 2 is strictly preferable, with 78.9% of participants preferring it after learning emissions information. In part 2, however, we further study the idea that many people would make the same changes by allowing them to customize the website.

3.2 Part 2

In part 2, we aimed to understand which aesthetic changes users tolerated by allowing them to customize the website to suit their ideal QoE-carbon footprint tradeoff. In Figure 7, we can see how often each of the alterations were chosen across all participants. The results showed a wide variety of preferences, with the most common change being to halt auto-play, though only 57.8% of participants chose that. Meanwhile, the least common was removing images, with only 1 participant (5.3%) choosing this alteration.

Like part 1, we break down these results by relation to the website, and we can similarly see differences in tolerance between groups in Figure 8. For example, students were more okay with grayscaled video (31.6%) compared to alumni (15.8%) or faculty/staff (5.3%), while faculty/staff were four times more likely to be okay with removing video (21%) than either students or alumni (both 5.3%).

Next, we look across participants at how much of a drop in carbon emissions resulted from their final customized website. The median drop was 67%, (65.16% and 92.69% for 25th and 75th percentile respectively).

The choices, along with descriptive answers, highlight that while most participants would like a lower carbon footprint associated with the websites they use, the exact implementation that suits their preferences varies widely. Most participants said that climate change is a pressing issue (median response of 1, or strongly agree, out of 5) and that they can see carbon emissions becoming an important factor in choosing which websites to visit (median response of 1, or strongly agree, out of 5). However, the exact changes they found tolerable (shown below in Figure 8), as well as their descriptions of the factors that affected their answers, varied widely. For example, some participants expressed that they prioritized the ability of the website to showcase the college: "I believe learning more about the college and the possibilities of what they can do here is slightly more important than the small CO_2 emissions that this one page on the website can bring.", while others expressed that the process made them rethink their preferences:"It made me think more carefully about what type of graphics are necessary".

Finally, participants were asked about the types of websites for which they could see themselves using this customization tool. The most common answer was news websites (4), followed by shopping websites (3). Other answers included Github, social media, and any other websites with a high density of promotional images and videos, such as restaurants.

4 DISCUSSION

First, we consider the implications of this study's results. The participants in this study showed significant agreement on the importance of carbon-aware websites and a willingness to incorporate carbon emissions into their quality of experience. However, it also showed little agreement on the specific website changes they would like to see to implement lower emissions websites. It would be easier for

Fig. 4. Customization panel where updates are shown to participant in real time

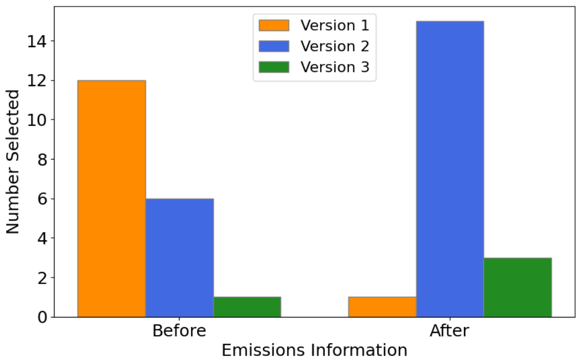

Fig. 5. Preferences Before & After Carbon Information

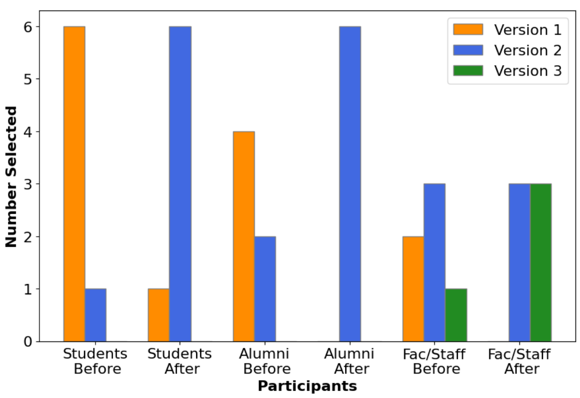

Fig. 6. Preferences Before & After Carbon Information

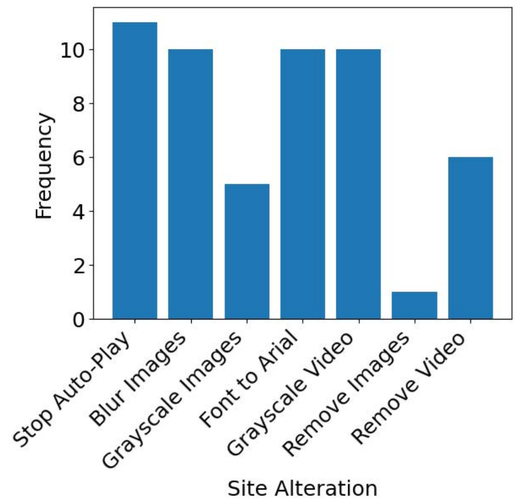

Fig. 7. Website Alterations Distribution

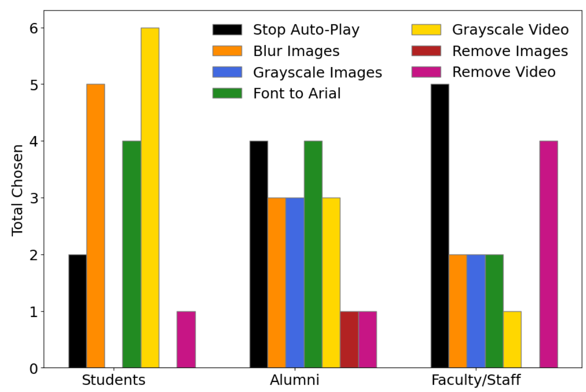

Fig. 8. Website Alterations by Group

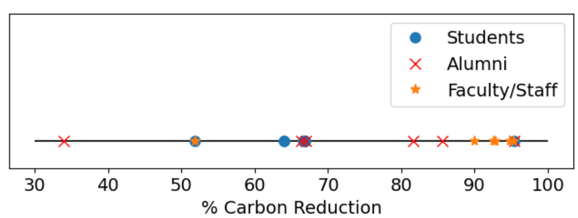

Fig. 9. Percent-wise Carbon Reductions in Users' Customized Versions

website designers if, for example, the vast majority of participants agreed that blurred images were fine. However, the lack of such "easy" changes highlights the importance of a personalized solution. For example, users could be asked about their willingness to incorporate emissions along with some questions about their personal aesthetic preferences to help a website decide how to best serve their requests. That is, there is promise that QoE can be considered a tunable parameter, but these results suggest that the tuning is best done per person.

Next, we consider biases and limitations of this study. First, we note the limited sample size and scope, as this study had 19 users and one website. Expanding to survey more users and include websites with a wider audience, such as national parks or news sites, would provide more insight into these findings. Further, we note that the academic community that uses our website tends to be particularly climate-conscious, so expanding to different populations might challenge our finding that most people find carbon emissions to be an important part of website usage. Next, as mentioned in

Section 2, our carbon measurements use the CO2.js tool, which assumes that the bytes transferred is proportional to emissions. While Sustainable Web Design justifies this assumption, it is controversial and not universally accepted—page weight does not capture the computational work done behind-the-scenes. We also note that we made our website modifications rather directly, e.g., removing images left a blank spot, which could have made the appeal of the corresponding versions lower than if we had, perhaps more realistically, redesigned the site based on each change. Finally, while this paper takes a step towards understanding user preferences and discussing QoE as a tunable parameter, a larger study with more participants and websites might allow us to draw conclusions about how to implement preference-based changes at scale, placing the study into a broader research agenda of practical deployment. Ultimately, this paper serves as motivation for a more expansive and robust study that takes into account the various limitations of our work.

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