Beliz Ilica.Sustainable User Interface Generation for Digital Devices: A Case Study. A Master's Paper for the M.S. in IS degree. July 2022. 53 Advisor: Fei Yu

The internet has become an integral part of people's lives. However, any digital activity results in energy consumption and greenhouse gas emissions, which are the prime drivers of global warming and climate change. The environmental cost calls for the practice of sustainable web design or green human-computer interaction. While there is substantial research on ways to reduce the energy consumption of the back-end information systems, such as data centers, few studies focus on the front-end information systems, such as web design. This study aims to analyze the impact of web design on energy consumption by conducting a case study on an institutional website. A set of major web tracking and performance metrics tools will be adopted to collect data on energy consumption, web performance optimization, web design, and user experience. Descriptive analysis of the data will help generate actionable insights into environmentally friendly user interface design strategies for digital devices.

Headings:

User Interfaces

Web Design

Web Development

Information Technology

Digital Technology

Human-computer Interaction

SUSTAINABLE USER INTERFACE GENERATION FOR DIGITAL DEVICES: A CASE STUDY

by
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A Master's paper submitted to the faculty
of the School of Information and Library Science
of the University of North Carolina at Chapel Hill
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Approved by

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Introduction

The internet has greatly transformed the way people provide and consume information. But, unfortunately, while making information communication faster, easier, and more accessible, our digital life produces CO2 gas emissions and consumes energy that can negatively impact the environment and exacerbate global climate change (Stolz & Jungblut, 2019) Today, with approximately 5 billion internet users, 2 billion websites, and 9 billion traffic, the internet has consumed nearly 4 million megawatt-hours of electricity and produced 3 million tons of CO2 emissions (Internet Live Stats, n.d) To prevent these numbers from going up every minute, it is critical to design and develop green web presences that reduce carbon emission and energy consumption.

To reduce the carbon footprint of the internet as a global warming agent, web designers and developers have started to promote the sustainable web design approach lately (Sustainable Web Manifesto, n.d.), which is to design digital user interfaces with principal concern for their capability of reducing carbon emissions and energy consumption by digital user interfaces. Therefore, in this proposed study, I aim to investigate the sustainability web design practices of the School of Library and Information Science official website to achieve the following goals:

1) To determine how web design shall be evaluated for sustainability

2) To assess the role of digital elements and aspects of user interfaces in developing a sustainable web presence

3) To generate strategies for sustainable user interface design on digital devices

Related Work

This section will investigate previous work and literature on sustainable user interface design and recognize other studies that were conducted in areas that are related to the purpose of this paper.

Sustainable Computing Systems

Sustainable information technology, also called green information technology, is the practice of designing and using computers, servers, and associated subsystems such as networking and communication systems efficiently with minimal environmental impact (Saha, 2014). One of the factors of green IT is sustainable computing which is concerned with reducing energy consumption by computers to minimize greenhouse gas emissions (Murugesan, 2008). Previous studies on energy-efficient computing systems propose hardware, software, and network solutions to reduce energy consumption.

Hardware

At the hardware level, studies investigated the power needs and usage of hand-held computers using several benchmarks to gain insights into the energy consumption of the devices (Sagahyroon, 2006). Two other studies suggested that digital displays were one of the components of electronic devices with the highest percentage of energy consumption (Fernandez et al., 2015; Park et al., 2012). To minimize the energy consumption of digital displays, researchers developed several techniques such as reducing the refresh rate, decreasing the color depth and brightness of displays, and investigated the advantages of high efficiency and long life of miniaturized and micro-LED chips (Choi et al., 2002; Kimmel, 2012; Wu et. Al, 2018). Other than displays, PC components such as processors and hard drives were also studied in previous work. Studies focused on identifying recent OS-level energy management techniques for adjusting power states of mobile processing units and techniques that consider interactions between displays and processors (Kim et al., 2018) and implementing energy-efficient storage systems to reduce the power consumption of hard drive disks (Oliech & Ruan, 2017).

Software

At the software level, several studies investigated the role of HTTP requests in web power consumption and suggested reducing the number of HTTP requests or the size of web components to save energy. Mainly, optimizing stylesheets and script files of a webpage to save energy was a highly recommended approach by previous research (Unlu & Yesilada, 2018). In addition, some researchers presented a framework to measure the energy used by mobile devices when rendering web pages (Thiagarajan et al., 2012) and investigated the reasons for slow web performance for mobile devices. Their findings revealed that images had most of the energy needed to render web pages. They suggested optimizing images and scripts for less storage size, faster rendering, and better web performance (Zakas, 2013).

Furthermore, researchers conducted comparative studies on the energy efficiency of different web browsers (de Macedo et al., 2020) and analyzed the benefits of proxy services in energy saving (Yu et al., 2010). One study observed the role of sustainability in web design and recommended alternative design options for the back-end information system on energy-saving (Willis et al., 2020). Two other studies even proposed frameworks for calculating the energy consumption of a website and explored the impact of energy-saving display modifications on perceived ease of use, quality, and performance (Boukema, 2017; Harter et al., 2004).

Network

At the network level, researchers proposed system algorithms to reduce energy consumption in cloud computing (Goyal et al., 2015), looked for ways to leverage renewable energy in data centers, and promote green cloud computing with reduced energy consumption (Deng et al., 2014; Diouani & Medromi, 2019), proposed schemes to optimize the energy consumption of servers and cooling systems in data centers (Ji et al., 2020; Chi et al., 2020), and utilized optimization software to minimize the energy consumed by the network and server sides of data centers (Al-Tarazi & Chang, 2020). Other studies explored the negative impact of internet traffic on our environment (Morley et al., 2018) and how social networks and search engines produce gas emissions (Pandikumar et al., 2012). Recent studies also investigated mobile edge computing as an alternative to mobile cloud computing. They propose a lightweight, energy-efficient computational offloading scheme to minimize the energy consumption of user devices and computation time (Zhang et al., 2020).

Sustainable Human-Computer Interaction (HCI)

Sustainability in the field of human-computer interaction (HCI) has become popular between researchers and practitioners over the last decade (Ali et al., 2014). This field intends to decrease the environmental impact of current unsustainable practices using interactive digital technologies to change human-computer systems and enhance the awareness to adopt user-centered design practices that consider ecological sustainability (Raghavan & Pargman, 2017). Previous research on sustainable HCI that focuses on understanding how individuals access, perceive, use, and dispose of technology allowed other studies to present environmentally sustainable technology and system designs that are competent with existing user practices (Hilty et al., 2011).

The current work on sustainable HCI was categorized into two approaches: "sustainability through design" and "sustainability by design." While the former is concerned with how technology design can support and promote sustainable behavior, the latter is concerned with designing the technology itself so that its use is sustainable (Mankoff et al., 2007). In the following section, I will investigate previous work that adopted the latter approach by focusing on the design of information technologies to reduce their impact on the environment through sustainable user interface design.

Sustainable User Interface Design

Despite intensive research on the energy-centric aspect of web usage at the hardware, software, and network levels, there is a lack of focus on the impact of web user interface design on the environment. Previous studies on energy-efficient web investigated internals of web page loading on mobile devices and suggested network-aware resource processing and adaptive content painting, as well as application-assisted scheduling to optimize the energy consumption of web page loading for mobile devices (Choi et al. 2019). Others suggested the need to explore the power consumption of mobile web interactions after webpage loading and implemented web interaction frameworks to enable personalized web interaction that adapts to user behavior changes and reduces energy use (Xu et al., 2018).

In addition, many studies implemented various website optimization techniques for usability purposes. One study focused on improving the usability of a university portal and suggested redesigns for website optimization (Xiong et al., 2021; Salvio & Palaoag, 2019), while another applied user experience (UX) design theories to develop responsive web design for security and emergency management website (Cosgrove, 2018). Likewise, other researchers suggested frameworks to contribute to the information systems of websites through aesthetic, functional, and symbolic dimensions to influence visitors' behaviors (Hartono & Holsapple, 2019) and identified web design attributes, particularly web layout and structure, as a major influence over user satisfaction (Dianat et al., 2019). Another study reviewed website design attributes such as visual design, navigation design, content design, and interactive design to reveal their influence on user attitude and behavioral intentions and to help e-commerce companies achieve their business goals (Ashraf et. Al, 2019). While these studies explore web performance issues for specific websites and propose user interface design solutions for improved usability, they do not investigate the relationship between user interface design elements and energy consumption and thus their design solutions are not concerned with reducing the carbon footprint of websites.

Similarly, researchers explored the role of web design elements on user interfaces in various settings. Studies were conducted to investigate how website layout and information architecture along with color temperature of an e-commerce tourism website influenced user experience design attributes and user intention, suggesting that a better UX could be accomplished with grid layouts and cool temperature colors (Oyibo & Vassileva, 2020). Another research focused on exploring elements on a corporate website to determine the site’s influence on sustainability perception. The findings of this study revealed that using blue colors on corporate websites had a significant effect on making the site and products appear sustainable (Flaschka, 2020). Although these studies enhance the understanding of the role and importance of web design assets, they do not provide meaningful solutions that would benefit not only the users but also the environment.

Existing literature proposed four indicators involved in sustainable web design: green hosting, search engine optimization, performance optimization, and design and user experience (Frick, 2016). Among these four indicators, using a green hosting service that is powered through renewable resources and optimizing website performance for search engines are the most impactful ways to reduce the energy consumption of a website (Frick, 2016).

However, even the most micro-level change of web elements can significantly impact the environment in the long term. For example, one study found that the web components such as text and multimedia content, colors, fonts, layout, structure, and interactivity design can significantly affect the web page's total weight - the size of all files used to create the page (Lawrance & Tavakol, 2007). Therefore, with an emphasis on these individual components, web designers can contribute to a sustainable web design with fewer carbon emissions.

This study will fill in this gap by investigating the four sustainability indicators, particularly the role of web optimization and user interface design components, to assess their impact on energy consumption and generate sustainable user interface design strategies with a case study for digital devices.

Methodology

We will conduct a case study by examining the sustainability of a selected institutional website using relevant tools and metrics to determine energy consumption.

Setting

The School of Library and Information Science (SILS) at the University of North Carolina (UNC) at Chapel Hill is an educational organization that celebrated the 90th anniversary of its establishment this year (SILS Home Page, n.d.). SILS relies highly on web technology and consumes significant amounts of data and energy for its day-to-day operations as an information school. Even though sites with the highest traffic belong predominantly to search engines, social media companies, and e-retail sectors, higher education websites also have considerable traffic with high visitor numbers and good bounce rates (Google Analytics Benchmark for Higher Education Websites, n.d. & Global Top Websites by Monthly Visit, n.d.). Likewise, with nearly 400 students, staff, faculty, and many visitors whointeract with the website frequently, the SILS website is presumably a high-traffic site. With each website visit, users produce gas emissions and use energy that negatively affect the environment. Therefore, it is crucial to implement sustainable web design practices on the SILS site to reduce its load on servers and end users' devices. To reduce the impact of SILS's digital presence on our environment, it is essential to take action with a sustainability plan that increase the energy efficiency of the site. SILS can reduce its digital carbon footprint and energy consumption by implementing recommendations from this study. In addition, the findings of this study can also apply to other similar schools on campus. Ultimately, the impact of all UNC websites on the environment can be minimized considerably.

Data Tools

We will adopt the following tools that have been used in previous studies to collectdata on the site's energy consumption and carbon emissions, web performance, content type and size, speed, user traffic, and screen time:

Website Carbon Calculator: is an online tool developed by a team dedicated to spread sustainable design approach across the web. The tool generates an estimate of a given webpage's carbon emissions using five data factors: data transfer over the wire, energy intensity of web data, energy source used by the data center, carbon intensity of electricity, and website traffic (Website Carbon Calculator, n.d.). Website Carbon Calculator provides insight on website efficiency and their impact on the environment. Several studies have utilized this tool to measure the carbon emissions of their site to assess its sustainability (Fang, 2007 & Faber, 2021).

Pingdom: is a widely used speed testing tool analyzing how quickly web pages load. It uses a global network of testing centers to determine a site's speed in more than 70 regions (Pingdom, n.d.). In addition, Pingdom provides insights on server response times, host- ing,

rendering and interaction times, content size by domain, and opportunities for improving page performance. One of the most important features of Pingdom is to break down the site based on content types and size and reveal which content component takes up the most storage size and consumes the most energy. Several studies used Pingdom to identify performance factors of websites and utilized the results tooptimize the web components and minimize the code (Asmaran, 2016; Gopinath et. Al 2016; Harper et. Al, 2008; Krol, 2020)
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Google Analytics: provides statistics and essential website usage analytics for search engine optimization. Particularly, website performance tracking and visitor highlights are helpful metrics for performance optimization. Additionally, website traffic and screen time data (Google Analytics, n.d.) will help determine the overall energy consumption of a web- site. Previous studies have utilized this tool to evaluate the overall usability of e- commerce and food composition sites (Hasan et. Al, 2009 & Pakkala et. Al, 2012) or to reveal how visitors interacted witha library website, including the most visited pages and the screen time of each page (Aspinal et. Al, 2021).

Drupal: The SILS website uses Drupal to manage its content. The user interface andlayout of the website are created mainly by customizing existing Drupal themes and incorporating modules. Therefore, we will use Drupal to investigate the theme files and modules to determine whether they are compliant with modern web standards, to analyze their effect on the site's page load speed, and to understand the reasoning behind the site's content layout. We will also investigate the features Drupal provides for energy-saving purposes and compare them with WordPress 's environmental sustainability practices.

Data Measures

To assess environmental sustainability, we will consider the total energy consumptionand CO2 gas emissions of the website and its components. Due to the size of the SILS website with more than five thousand webpages, we will use the weighted average of the top 10 most visited webpages to assess the environmental sustainability of the entire site. To provide a more in-depth analysis of the site's energy consumption and reveal the role of each component, we will collect various data on the SILS site. As shown in the table below, the data we aim to collect will focus on two levels (i.e., network and software) and four measures (i.e., performance optimization, search engine optimization, web design and user interface design, hosting). The collected data will reveal the site's web performance, content type and size, site speed, user traffic, page screen time, content quality, and impact of the hosting and content management services and their load on servers and end users' devices.

Overview of data measures

Level	Data Measures	Metrics	Tool
Software	Performance Optimization	• Page speed and weight • Content size (imagery, text, motion in kB) • Code size (HTML, CSS, JavaScript) • Number of HTTP requests	• Pingdom • Google Analytics
	Search Engine Optimization (SEO)	• Findability • Content quality (links)	• Google Analytics
Network	Web Design & User Interface Design	• Size of design assets (color, fonts, layout, graphics in kB) • Media content optimization (images, videos, interactive elements, gifs)	• Drupal • Pingdom
	Hosting	• Green Hosting	• Pingdom

Data Analysis

This study will analyze the collected data quantitatively using Microsoft Excel. Descriptive statistics will be provided for each of the data measures. Sustainable web design strategies and recommendations will be generated based on the results.

Risk and Ethical Considerations

Since this project does not rely on any individuals and the final deliverable will not affect anyone directly, there are minimal ethical concerns. However, there are a few risks to consider when conducting the study. For this study, I will occasionally access the SILS website's development site during the sustainability evaluation phase. By granting me access to the development site for this project, SILS IT takes the risk of a potential data breach.

To ensure information safety and maintain the site's current design, the development site requires login credentials. The SILS IT team must allow or deny access to individuals by authorizing their credentials. This step requires signing into the development site and adding the credentials to the 'users' page. Currently, only a few individuals have access to the development site, including the IT and communications coordinator director. As a current student employee who also worked on the SILS website for previous projects, my credentials were already added to the system, so I have access to the development site. Since students are not allowed to access the development site and the information on the development site is not public, I will log in as a university employee every time I want to access the site and protect the information presented on the site from the public.

Although I am currently a student employee and was assigned to other projects related to the SILS website in the previous year, I will not be conducting this study for my employer. Furthermore, even though I will use my employee status to access the necessary tools to complete my project, I will not receive any funding or compensation for my work from SILS. The time I will allocate to this project will not be included in my work hours, so I do not anticipate a conflict of interest. The only advantages of my status as a school employee will be the experience, I gained working on the site with previous projects and the existing credentials that grant me access to some data tools.

Impact and Limitations

Potential Impact

This project can potentially impact the overall digital footprint of SILS and eventually of the entire university. The findings of this study will present the total energy consumption of the SILS website and will create the base for recommendations that can significantly reduce the energy consumption and the carbon footprint of the site. By implementing all or some of these recommendations, SILS can take a step towards establishing a greener web presence that can lead other schools in the university to engage in sustainable web design practices as well. Although sustainable web design strategies will be generated based on the sustainability evaluation of the SILS site, it is possible to conduct further studies on other websites that represent different organizations and entities within the university to invest in sustainable web design practices. While these recommendations would not guarantee a web presence that is entirely environmentally friendly, in the long term, they have the potential to influence other actions that would contribute to the wellbeing of our environment.

Limitations

This project is planned to have three main sections that will be presented with a written report: background research, sustainability evaluation, and recommendations. The allocated time to complete all three sections of the project is eight months.

Even though this project could benefit from a usability evaluation to assess the effectiveness of design elements on the SILS website, I will not be conducting one due to time constraints. Instead, I will evaluate the design assets' role and weight to identify their environmental impact. Furthermore, this project will include evaluations and suggestions on search engine optimization and web hosting to build a comprehensive and far-reaching report. However, the focus of the study will be the web design and user interface design aspects of the web and not so much search engine optimization and hosting.

After I generate recommendations for sustainable web interface design, I will not be implementing the changes to the SILS website for several reasons. First, due to limited time, it would not be possible to complete the background research, sustainability evaluation, strategy generation, and implementation of the proposed changes to the website. Since the implementation phase would take a significant time, at least three more months would be needed to complete this step. Second, since I do not have a web development background and did not receive training on the subject, my skills would not be sufficient to implement the changes I aim to propose. If the changes were to be applied, it would be ideal for someone experienced in web development to undertake this task. Third, the proposed changes could be infeasible to implement for various reasons. First, implementing the suggested design strategies could involve noticeable changes to the current interface that may intervene with the website theme and objectives. Moreover, additional funds would be needed if SILS decided to implement the changes. Since the amount of capital can increase based on how the changes are implemented and by whom, SILS may not be willing to support this phase of the project due to financial restrictions.

Results

The following section will present the findings of the sustainability evolution of the most visited 10 pages of the SILS website. We used Google Analytics to determine which ten SILS website pages had the highest number of screening and visitors over the past year. The table below presents the top 10 most visited web pages along with the path and average time spent on the page.

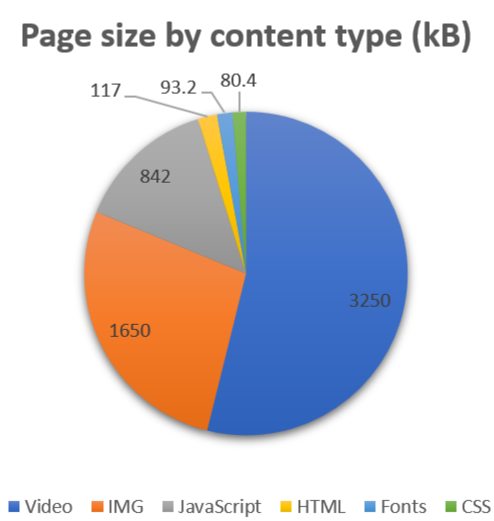
Top 10 Sils webpages with the highest views

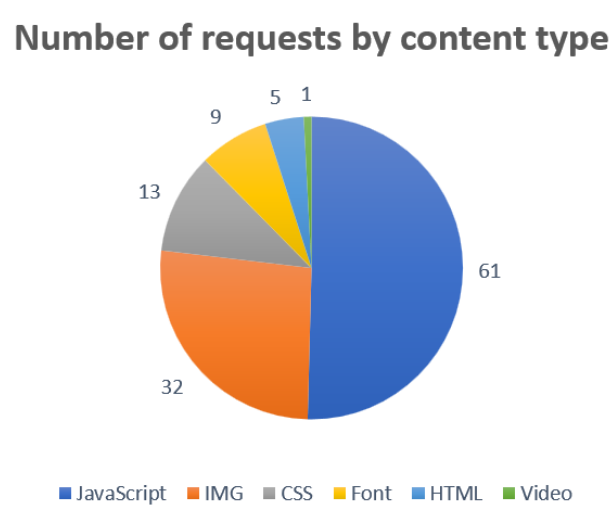
Page	Path	Page Views	Avg. Time on Page
1. Home page	(sils.unc.edu)	46,985	00:00:56
2. Courses	(sils.unc.edu/courses)	29,433	00:01:36
3. MSIS	(sils.unc.edu/programs/gradute/msis)	24,365	00:01:10
4. MSLS	(sils.unc.edu/programs/graduate/msls)	22,540	00:01:02
5. Admissions	(sils.unc.edu/programs/graduate/admissions)	21,687	00:03:41
6. ITS VR Lab	(sils.unc.edu/it-services/software/its-virtual-lab)	21,416	00:05:25
7. ITS FAQ	(sils.unc.edu/it-services/personal-computer-faq/wireless)	15,990	00:07:12
8. Programs	(sils.unc.edu/programs)	13,407	00:00:26
9. BSIS	(sils.unc.edu/programs/undergraduate/bsis)	10,194	00:01:08
10. Faculty Directory	(sils.unc.edu/directory/faculty)	9,212	00:01:16

SILS Home Page

With nearly 50,000 views in a year, the SILS homepage is the most viewed page of the SILS site and attracts visitors from all around the world (Google Analytics, n.d.). According to Website Carbon Calculator, the SILS home page is dirtier than 92% of web pages tested by the tool and produces 2.51 grams of CO_2 every time users visit the page. With 46,985 views annually, the CO_2 production of the home page equals 117,932 kg, which approximately equals to 341kWh of energy. The page uses BOG standard energy.

In 2021, Web Almanac revealed that a webpage sits at approximately 4MB at the 75th percentile and almost 8MB at the 90th percentile on desktop devices. With a size of 6.12MB, the home page's weight is close to the upper 90th percentile page size. (Helvetica, 2020) Based on Pingdom, the distribution of home page weight and the total number of page requests are shown in the following charts:



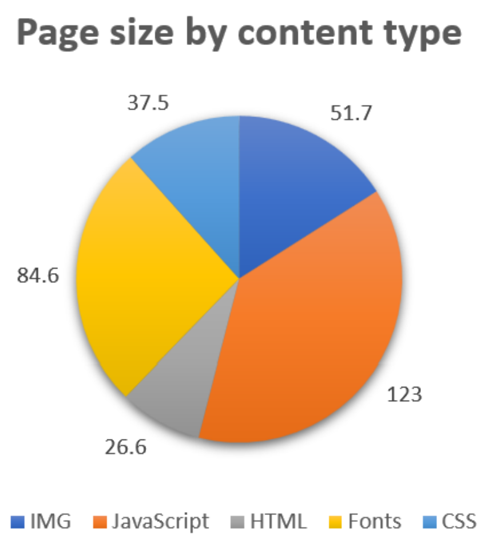


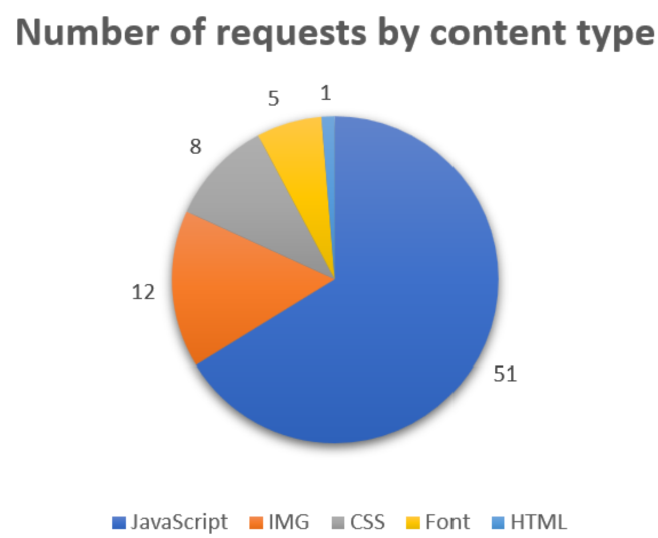
As seen above, video and images are the elements that take up the most space on SILS homepage with a total of 4.90MB. The next element that is heaviest after the media elements is JavaScript with 842KB, followed by HTML, fonts, and CSS with a total of 290.6 KB of space. 41% of 148 total requests is made by JavaScript, 21% by the image elements, 8% by CSS, and 9% by the font, HTML, and CSS files.

Courses

The second most visited page of the SILS site is the courses page with nearly 30,000 views per year. The page is cleaner than 93% of web pages tested by the Website Carbon Calculator tool and produces 0.007g of CO2 with every visit. Based on the annual visit amount, this page produces 2.06031 kg of CO2 every year. The page uses BOG standard energy.

With a size of 327.4KB, the page is considerably light weight compared to the average page weight. As shown in Table 2.2, JavaScript is the heaviest element on the page with 123 KB and 51 page requests, followed by fonts with 84.6 KB and 5 requests, images with 51.7KB and 12 requests, CSS with 37.5 KB and 8 requests, and HTML with 26.6 KB and 1 request.

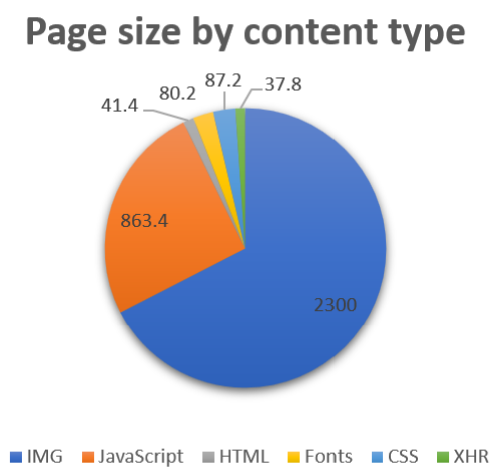


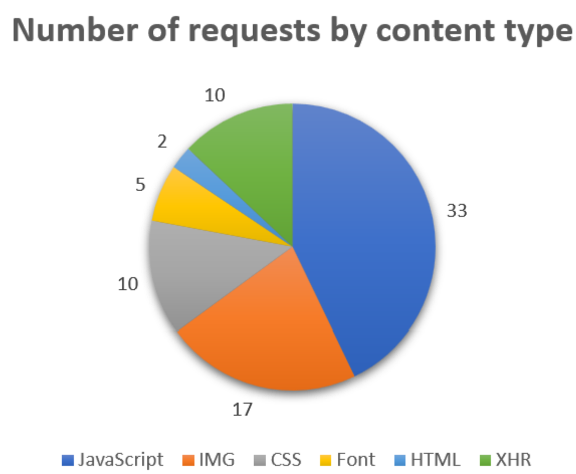


Master of Information Science (MSIS)

The MSIS page is the third most visited page of the SILS site and is dirtier than 56% of the web pages tested. The page produces 0.57g of CO2 with each visit and uses BOG standard energy. Over a year, with 24,365 page views, the MSIS page produces 13.88805 kg of CO2.

The MSIS page is 2.3 MB in size and has a total of 77 page requests. As presented in the chart below, the images on the MSIS page take up half of the page distribution with 1.2 MB and 17 page requests. Next, JavaScript takes 863.4KB and 33 page requests, becoming the second heaviest content type on the page. CSS weights 87.2 KB and has 10 requests, followed by fonts with 80,2KB and 5 requests, HTML with 41.4KB and 2 requests and XHR with 37.8KB with 8 requests.

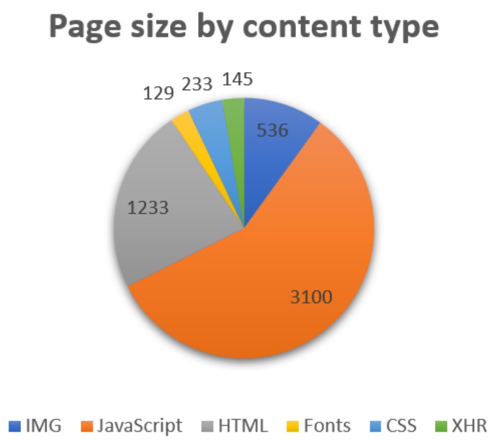


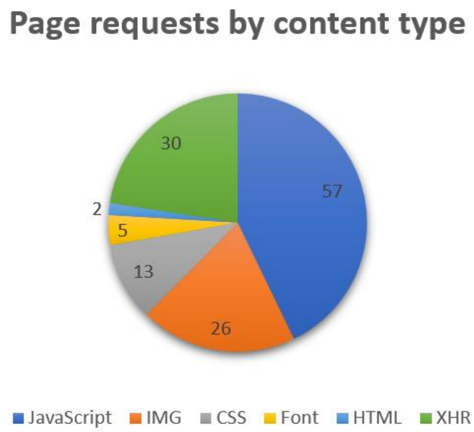


Master of Library Science (MSLS)

Similar in design to the MSIS page, the MSLS page is dirtier than 76% of web pages tested by the Web Carbon tool. The page produces 1.04g of CO2 every time someone visits the page and uses BOG standard energy. With 22,540 views over a year, the MSIS page is responsible for the production of 23,4416 kg of CO2 annually.

The total page size is 4.3 MB, and the total number of page requests is 144. The chart below shows that almost 75% of the total weight is due to JavaScript with 3.1MB. After that comes images with 536 KB, the CSS with 233KB, XHR with 145KB, fonts with 129KB, and HTML with 123KB. Similarly, JavaScript holds the majority of the requests with 57 page requests. The next highest number of requests belong to XHR and Images with 30 and 26 requests, respectively. CSS has 13 requests, font has 8 requests, and HTML has 5 requests.

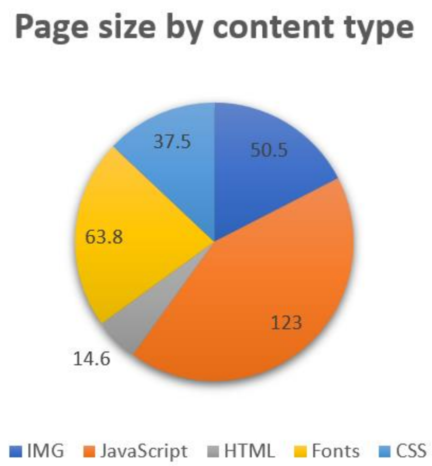


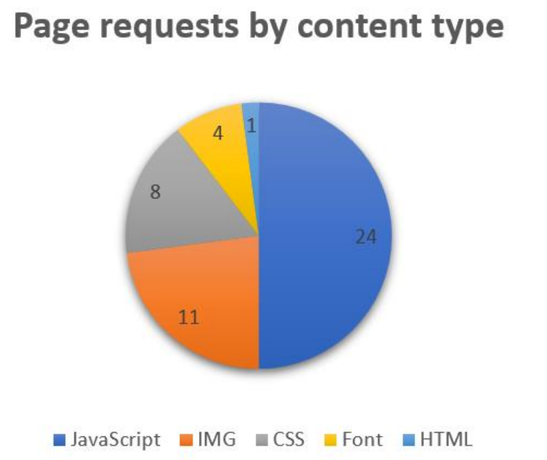


Admissions

The admissions page is considerably clean compared to 94% of web pages tested by Web Carbon Calculator tool. The page produces only 0.07g of CO2 with each visit and uses BOG standard energy. Over a year with 21,687 views, the admissions page produces 1.51809 kg of CO2.

The admission page's size is 293,4KB with a total of 49 page requests. The largest content type on this page is JavaScript with 123KB, followed by fonts with 63.8 KB. Images have a size of 50.5 KB, CSS has 37.5 KB, and HTML has 14.6 KB. 24 of the total page requests belong to JavaScript, 11 to images, 8 to CSS, 4 to font, and 1 to HTML.

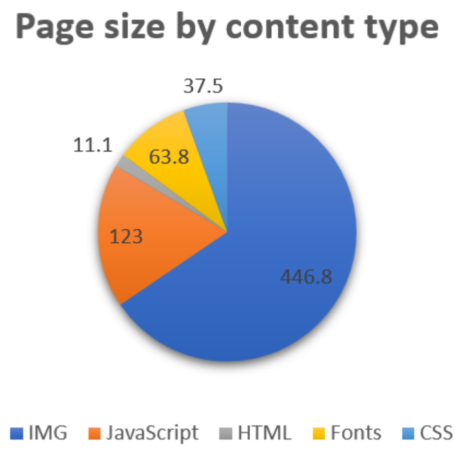


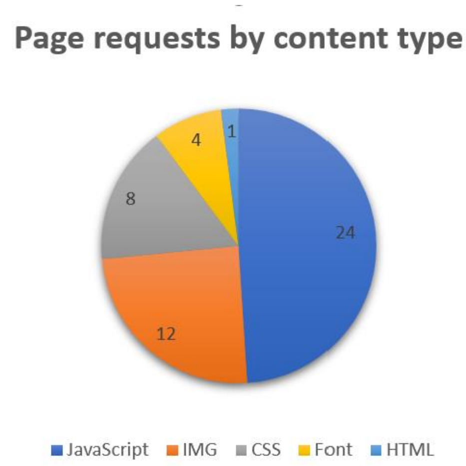


ITS VR Lab

The ITS Virtual Lab on the SILS site is cleaner than 85% of web pages tested and produces 0.16g of CO2 with each visit. The page uses BOG standard energy. Over a year with 21,416 page views, this page produces 3.42656 kg of CO2.

The size of this page is 686.3 KB and the total number of page requests is 50. The content size by content type distribution below reveals that images take 65% of all weight with 446.8KB, followed by JavaScript with 123KB, font with 63.8KB, CSS with 37.5 KB, and HTML with 11.1KB. 24 of the 50 page requests are from JavaScript, 12 from the images, 8 from the CSS, 4 from the font, and 1 from the HTML.

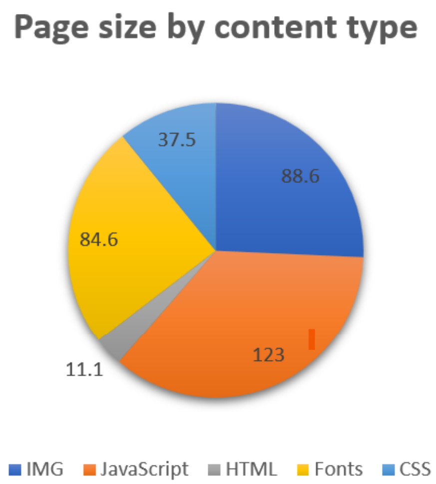


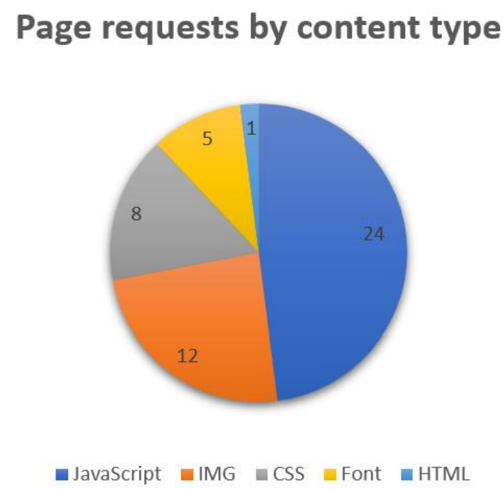


ITS FAQ Wireless

This page is cleaner than 92% of the web pages tested with the Carbon Calculator tool and produces only 0.08g of CO2 with each visit. The page uses BOG standard energy like the rest. Over a year with 15,990 views, the total amount of CO2 produced by this page is 1.2792 kg.

This page weighs 348.8KB and has 51 page requests. JavaScript weights 123KB with 24 page requests, images weight 88.6KB with 12 requests, font weights 84.6KB with 5 requests, CSS weights 37.5 KB with 8 requests, and HTML 11.1KB with a single request.

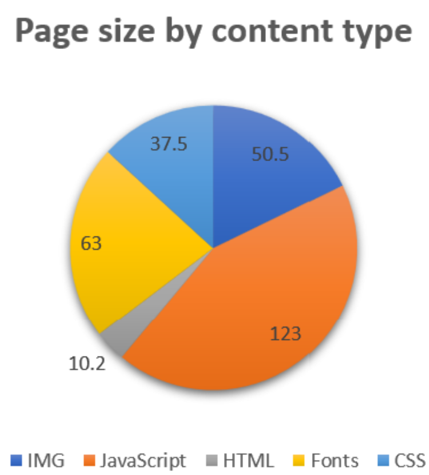


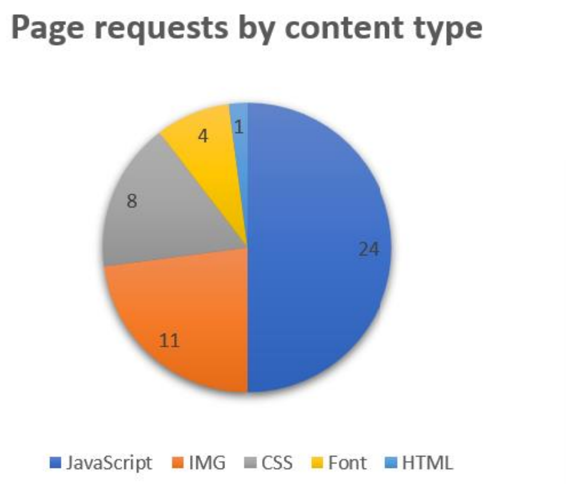


Programs

Based on the Website Carbon Calculator tool, the programs page is cleaner than 88% of web pages tested. The page produces 0.15g of CO2 and uses BOG standard energy. In a year with 13.407 views, the programs page produces 2.01105 kg of CO2.

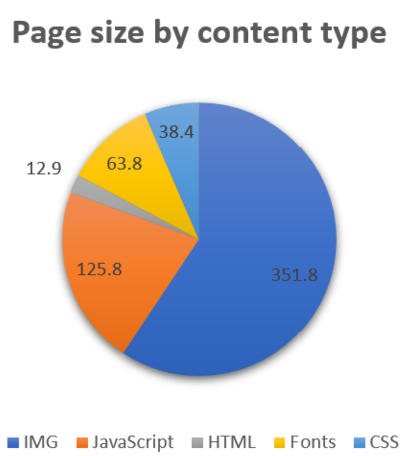
Being one of the smallest pages on the top ten list, the programs page weighs 289KB and has 49 requests. The heaviest content type on the page is JavaScript with 123KB, followed by font with 63KB, image with 50.5KB, CSS with 37.5KB, and HTML with 10.2 KB. As for the requests, JavaScript has 24 requests, image has 11 requests, CSS has 8 requests, font has 4 requests, and HTML has 1 request.

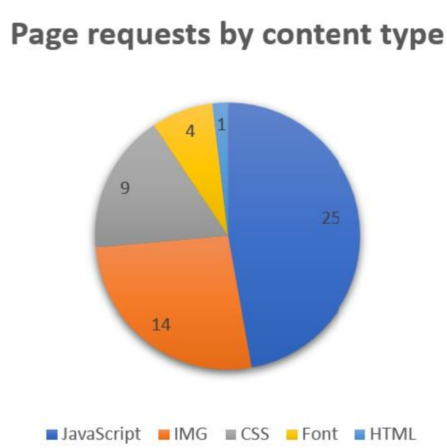




BSIS

The BSIS page is cleaner than 86% of web pages tested by the Carbon Calculator tool. The page produces 0.14g of CO2 every time someone visits and uses BOG standard energy. Over a year with 10,194 views, the programs page produces 1.42716 kg of CO2. The page size of the page is 596.6KB with 54 page requests. Images account for more than half of the page's weight with 351.8KB. Following images, JavaScript's weight is 125.8KB, followed by fonts with 63.8 KB, CSS with 38.4 KB, and HTML with 12.9 KB. 25 of all page requests are by JavaScript, while 14 by images, 9 by CSS, 4 by fonts, and 1 by HTML.

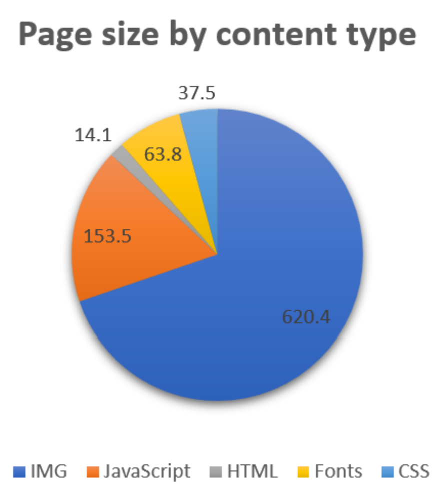


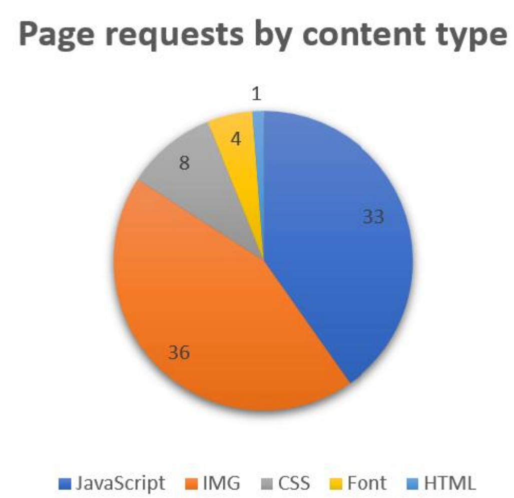


Faculty Directory

The faculty directory page is cleaner than 79% of web pages tested and produces 0.20g of CO2 with each page visit. The page uses BOG standard energy. Over a year with 9.212 views, this page produces 1.8424kg of CO2.

The faculty directory page has a size of 893.3KB and has 83 page requests. Images are the heaviest content types on this page with 620.4KB and 36 page requests. Following images, JavaScript accounts for 153.5KB and has 33 requests while fonts weight 63.8KB with 4 requests, CSS weights 37.5KB with 8 requests, and HTML weights 14.1KB with 1 page request.





Discussion

As the results of our sustainability evaluation suggest, while some pages are smaller in size than others, the sum of the top ten pages' weight equals 16,15MB. Considering the SILS page has over 5,000 web pages, the sum weight of all pages would be significantly high.

The CO2 production of the top 10 pages of the SILS website over a year totals up to 168,87 kg of CO2. This amount is equivalent to greenhouse gas emissions from 3,638 gasoline-powered vehicles driven for one year, 1,899,701 gallons of gasoline consumed, 18,679,111 pounds of coal burned, 2,127 homes' energy use for a year, 2,053,649,249 smartphones charged; and is equivalent to the carbon sequestered by 279, 156 tree seedlings grown for 10 years, and 19,980 acres of U.S forests in one year (the United States Environmental Protection Agency, n.d)

Based on gathered data, the SILS home page, also the landing page, is the heaviest page of the entire site with 6,12 MB in size, and the dirtiest with 117,932 kg of annual CO2 production. Following the SILS home page, MSLS and MSIS pages produce the most CO2 with 23,447kg and 13,888kg, respectively, and are relatively heavy at 4.3MB and 2.3 MB in size. While other pages are all sized below a megabyte, the ITS VR Lab and courses pages together weigh almost 1MB and produce a total of 5.5 kg of CO2 over a year. The results also suggest that while the Programs page is the lightest in size, the ITS FAQ page produces the least CO2 with only 1.28 kg. The data suggest that most of the pages tested were either image or JavaScript dominant in terms of page weight, and all had JavaScript as the content type with most page requests.

Although individual pages may not affect the environment drastically, reducing the size of even the lightest page can have a greater impact on the overall size of the website, and thus its environmental sustainability. The next section will investigate ways of reducing the overall size and energy consumption of the ten pages that were analyzed, and generate user interface design suggestions that would help the SILS site reduce its environmental footprint.

Page Size and CO2 production

Page	**Size**	**Annual CO2 production**
SILS Home page	6.12 MB	117,932 kg
MSLS	4.3MB	23,447 kg
MSIS	2.3MB	13,888kg
Faculty Directory	893,3KB	1,8424kg
ITS VR LAB	686,3KB	3,426 kg
BSIS	596,6KB	1,427kg
ITS FAQ	348,8KB	1,279kg
Courses	327,4KB	2,060 kg
Admissions	293,4KB	1,518kg
Programs	289KB	2,011kg

User Interface Design Suggestions

To reduce the overall size of the SILS website, it is important to start with the design of the top 10 most visited pages that have the greatest impact on our environment. To do so, we will consider the data we gathered in the results section of this paper and propose alternative solutions and suggestions to reduce the page size on web and user interface design levels. The recommendations will start with areas that apply to all 10 pages of the site and continue to more specific recommendations that apply to individual pages if applicable.

Sitewide Suggestions

Fonts

All content types used on a webpage, including fonts, need to be loaded on a page and are requested to the server via HTTP. To make a website more sustainable, the number of HTTP requests must be minimized (Smith, 2021). Based on our findings, the number of HTTP requests by fonts varied from 5-10 for tested pages. To reduce the number of HTTP requests by the site's fonts, Merriweather for headings and Source Sans Pro for body text, SILS can switch to more environmentally friendly font families. According to Smith (2019), Arial, Times New Roman, Courier New, Georgia, Verdana, and Helvetica are default fonts on both Macs and PCs. Thus, they do not require additional requests when loading. By switching over to one of these fonts, the site's environmental impact can be reduced.

Site Colors

Considering the rise of OLED screens that are capable of lighting themselves based on pixels instead of using backlighting, it is important to make web design choices that would save energy. OLED screens light up when pixels are needed and turn off when the screen is black. That being said, switching from a white background to black would save pixels that are energy-consuming (“Environmentally Friendly Color Palettes”, 2021). A basic exploration of the SILS site’s content management system, Drupal, reveals the theme colors used. The most dominant two colors of the site are Carolina Blue (#007fae), navy (#083a5b), and white (#fffff) colors. Other accent colors include orange blood (#ce491c) and dark green (#538240). All pages of the SILS site, including the top ten pages we investigated for this study, have a white background with gray text and blue design elements, including the header and the footer. While the white background alone is not an ideal design choice for an environmentally friendly website, the blue theme colors also negatively impact the site’s overall energy consumption. It is found that blue pixels use around 25% more energy compared to red and green pixels (Greenwood, n.d.). SILS site colors would consume significant energy when screened on OLEDs.

Hosting

According to the Website Carbon Calculator tool, the SILS site uses BOG standard energy instead of green renewable energy resources. If the site used green hosting, it would emit 9% less CO_2, which is a significant amount considering the total gas emissions. Switching over to a greener host could reduce the impact of the SILS site.

Media Elements

Tom Greenwood explains in his blog: “video is increasingly popular as a content format on the web, and it is by far the most data-intensive and processing intensive form of content” (Greenwood, n.d.). He also suggests that a website with video content can be one or two orders of magnitude heavier than a website without any video content, resulting in greater energy consumption that is harmful to the environment (Greenwood, n.d.). While the SILS site is relatively low in video content, there are several pages using embedded YouTube video galleries. As embedded videos add an additional piece of code to webpages that increase the size and number of HTTP requests (“Do Videos Impact Your Website’s Load Time?”, n.d), it may be a cleaner alternative to replace video galleries with image galleries.

Like videos, images take up considerable space on web pages and are used commonly in web design. While adding character to pages, they can be heavy on the CPUs with their contribution to the amount of data transferred on the web pages (Greenwood, n.d.). The SILS website uses images frequently, which takes up a lot of the site’s weight. To reduce the image file sizes, the file format can be switched to WebP instead of JPG or PNG images. According to the article “Sustainable Web Design: Can You Lower Design’s Environmental Impact?”, the WebP file format reduce image file sizes by 25-35% while increasing page speed and performance. It is also helpful to reduce the size of all images used on the site via several optimization tools including image compressors.

Individual Suggestions

SILS Home Page

The SILS landing page has the most appealing and complex page design on the SILS site with several content types including video banners, custom content types such as multicolored carousel blocks, video galleries, and query bars for search purposes, and dynamic alumni quote carousel. Unlike other pages on the site, the home page uses all four of the theme colors: orange blood (#ce491c), dark green (#538240), Carolina web blue (#007fae), and navy (#083a5b).

As the results suggested, the most energy-intensive content type on the SILS landing page is the video with over 3MB in size. This is mainly due to the large video banner with autoplay, unique to the landing page. To reduce the overall size and loading time, the video banner can be shortened or replaced with either an image gallery or static color block. While the video helps introduce the department and its resources to prospective and current students, it’s significantly large with its duration of over a minute, and its eye-catching nature can distract viewers from their purpose for visiting the page. Based on Google Analytics, the average time spent on this page is one of the longest at 56 seconds, which may be due to the length of the banner video. Therefore, if not removed altogether, adjusting the length of the video can be an effective solution in reducing the size and the environmental impact of the page. In addition, removing the autopay would reduce the amount of video played, and thus help save more energy.

The next heaviest content type on this page is images with 1.6MB in size and 32 requests. To decrease the file size of images on the SILS page, the video thumbnails can be removed, and images used in multicolor text blocks can be removed or overlayed with a darker color to reduce OLED energy consumption.

MSLS & MSIS

Two of the most popular program pages on the SILS site, MSIS, and MSLS pages are energy intensive with a page weight of over 2MB. Both pages include a full-sized image banner with a title, a sidebar menu with links, buttons, and media elements including images and videos. MSLS page has more video content than the MSIS page, and thus its' heavier and requires more energy to load on the server. To reduce the size of both pages, the video galleries can be replaced with external links. This would help reduce the heavy code weight and load the pages faster. In addition, lighter accent colors used on headers and links can be changed with darker colors such as navy blue. Since the underline text-decoration is already in use, darker colored links would be easily recognized as 'clickable' content. Since the images on both pages do not serve any particular purpose, except for the ALA accreditation logo, they can be removed.

Faculty Directory

The faculty directory page plays an important role in identifying faculty members and learning about their expertise and interests. Although this page has many images with 36 HTTP requests, the images are essential in identifying faculty members. Therefore, aiming to reduce the size of the page rather than the number of HTTP requests would be ideal. To reduce the page size, images can be optimized to hold fewer pixels or can be styled as black-white images. Another design decision that would help reduce the size would be to remove the blue bottom border of images.

ITS VR Lab

This page is relatively simple compared to other pages, and only has a weight of 686KB. Most of the pages' weight is caused by a single JPG image. To reduce the page size, this image can be removed altogether as it does not serve any purpose. Another solution could be to remove the 'Recent News' section at the bottom of the page. This section is repeated on several other pages as well, however, it is mostly redundant and can be eliminated. By removing it from the ITS VR Lab page, the number of HTTP requests can be decreased to save more energy.

BSIS

Compared to other program pages, the BSIS page produces less CO2. The main reason behind this is the minimal use of imagery and videos. To establish even a cleaner design for this page, the green and blue accent colors of the buttons and full-sized sections can be switched with darker colors. This would also help achieve a higher accessibility score as it would strengthen the contrast between the text and its background. The large banner image can also be reduced in size with optimization or can be combined with a darker overlay color to reduce the light-colored pixels that consume more energy.

ITS FAQ

The ITS FAQ page is relatively simple in design and has minimal media elements. However, since the page has the longest view time with more than 7 minutes, it is important to consider ways to reduce the overall size and HTTP requests to save energy. A quick and easy solution to reducing the page size would be to remove the ‘eduroam’ image that is listed within the instructions for connecting to eduroam. However, the image’s content does not provide valuable information for users and thus can be removed to save KBs. To reduce the number of HTTP requests, some of the external links can be replaced with the link’s content.

Conclusion

This study states the importance of web design in environmentally sustainable web presences and provides insights on sustainability on various levels. We study and analyze the environmental impact of web design on total energy consumption by conducting a case study on the SILS website. We investigate sustainability indicators such as web hosting, performance optimization, and particularly web design and user experience and utilize multiple web performance and tracking tools to analyze the impact of each indicator on the overall energy consumption and carbon emissions of the site. Descriptive data analysis help generate actionable insights into environmentally friendly user interface design strategies for digital devices, which can help SILS and similar departments to reduce their carbon footprint and save energy.

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