Bachelor's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Architecture and Design
Department of Design

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Sustainable Web Design Guidelines

Reducing carbon emissions from the Web by raising awareness, expanding available research, and providing practical recommendations for web designers.

Bachelor's thesis in Web Development
Supervisor: Carlos Vicient Monllaó
May 2023

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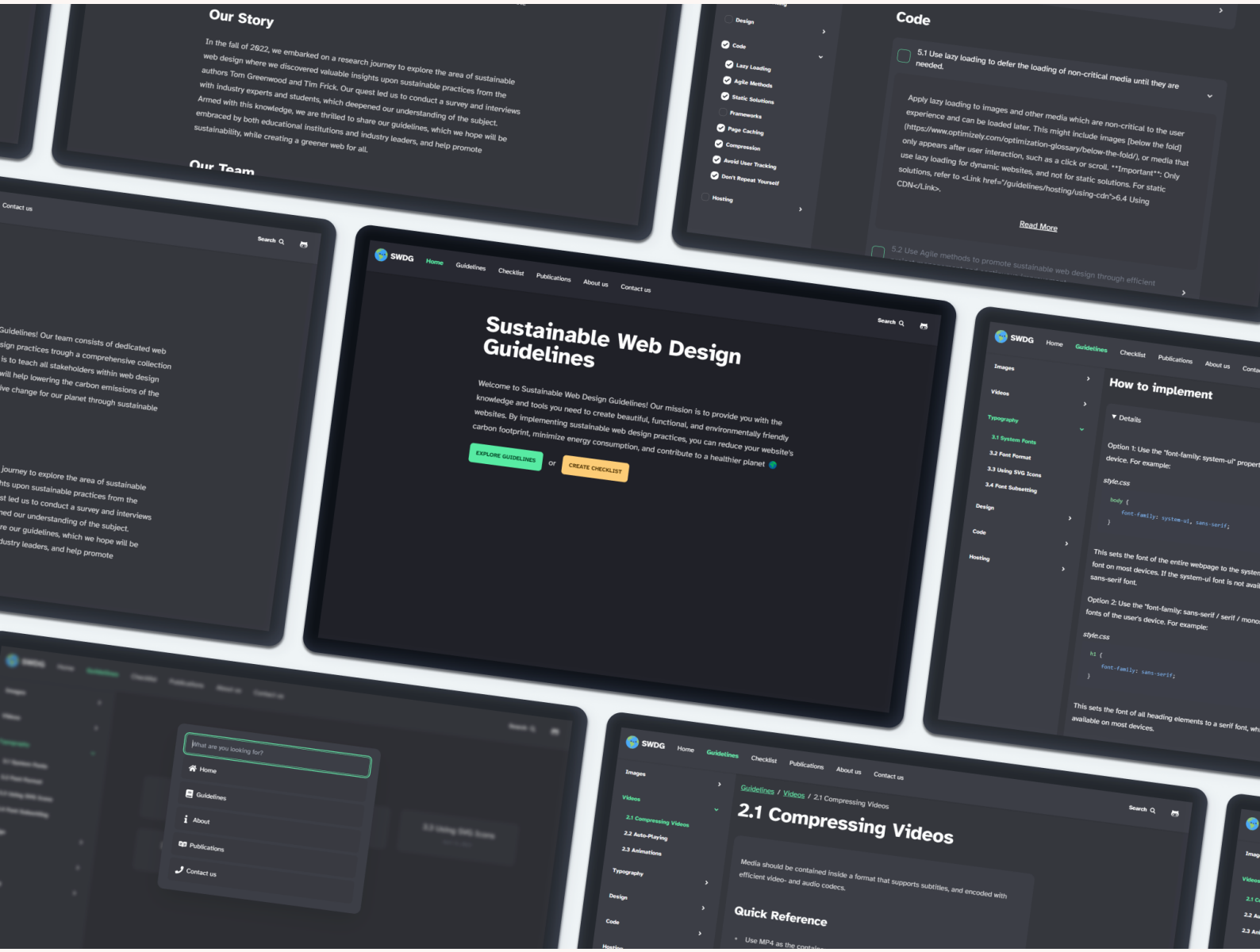

Spring 2023, Bachelor's degree in Web Development

Product Owner: The Department of Design

Supervisor: Carlos Vicient Monllaó

NTNU | Norwegian University of Science and Technology

Foreword

We are proud to present our bachelor thesis in web development, completed in the spring of 2023 at the Department of Design at NTNU in Gjøvik. Our thesis reflects our high ambitions and exceptional teamwork and aims to contribute to the reduction of carbon emissions from the Web by raising awareness, researching challenges, and creating guidelines for Sustainable Web Design. The goal is to create a comprehensive set of guidelines for all stakeholders involved in website development. The thesis consists of three studies that examine different aspects of Sustainable Web Design and includes developing and hosting a website for disseminating guidelines.

We want to use this opportunity to thank our tutor, Carlos Vicient Monllaó, and our product owner Yavuz Inal. Thanks to their invaluable guidance and support, we are thrilled to announce that we have successfully published one research paper and submitted a second one. Working with our mentors has provided us with valuable knowledge and experience for future endeavors. We would like to express our deep appreciation for the outstanding collaboration we have had with our tutor and product owner. Their expertise and support have been instrumental in the success of our thesis. We would also like to extend our gratitude to all the participants who generously shared their insights and feedback with us, which were invaluable in shaping our research and guidelines. Thank you all for your contributions!

May 15th 2023, Gjøvik

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Abstract

Title: Sustainable Web Design Guidelines

Date: 15.05.2023

Participants: Henrik Landgraff Granum, Sivert Gullberg Hansen, Ola Hulleberg, Magnus Moen

Supervisor: Carlos Vicient Monllaó

Employer: Department of Design (ID) at Norwegian University of Science and Technology in Gjøvik

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This thesis focuses on the environmental impact of the Internet and the need for Sustainable Web Design practices. The Web demands significant computational power and electricity, which contributes to climate change. The goal of this thesis is to minimize the carbon footprint of the Web by investigating the awareness, practices, challenges, and barriers faced by both industry and academia. This thesis presents research conducted for Yavuz Inal on behalf of the Department of Design at The Norwegian University of Science and Technology. It is divided into three studies: Awareness and Practices, Challenges and Barriers, and Guidelines. The studies in this thesis investigate Sustainable Web Design, by examining developers' awareness and practices, identifying current challenges and barriers to implementation, and proposing practices that should be included in dedicated guidelines for Sustainable Web Design. By studying these aspects, the thesis intends to provide practical guidelines for Sustainable Web Design to help stakeholders prioritize sustainability in web solutions and collectively reduce the carbon footprint of the web. Additionally, the research findings will be presented at relevant Human-Computer Interaction (HCI) conferences, and disseminated along with the guidelines on a website developed by the group.

Abstract (Norwegian)

Tittel: Rettningslinjer for bærekraftig webdesign

Dato: 15.05.2023

Deltakere: Henrik Landgraff Granum, Sivert Gullberg Hansen, Ola Hulleberg, Magnus Moen

Veileder: Carlos Vicient Monllaó

Oppdragsgiver: Institutt for design ved Norges teknisk-naturvitenskapelige universitet i Gjøvik

Fag: Webutvikling

Stikkord: Bærekraftig webdesign, Utfordringer og barrierer innen bærekraft, Bevissthet om og praksis for bærekraft, Retningslinjer, Digitalt karbonavtrykk, Klimaendringer, Miljøpåvirkning, Bærekraft

Antall sider: 100 + 70

Antall ord: 27 921

Antall vedlegg: 7 (+ 4 konfidensielle)

Denne bacheloroppgaven fokuserer på miljøkonsekvensene av Internett og behovet for bærekraftig webdesignpraksis. Nettet krever betydelig datakraft og elektrisitet, noe som bidrar til klimaendringer. Målet med denne bacheloroppgaven er å minimere nettets karbonavtrykk ved å undersøke bevissthet, praksis, utfordringer og barrierer som både industrien og akademia står overfor. Denne bacheloroppgaven presenterer forskning utført for Yavuz Inal på vegne av Institutt for design ved Norges teknisk-naturvitenskapelige universitet. Den er delt inn i tre studier: Bevissthet og praksis, Utfordringer og barrierer og Retningslinjer. Studiene i denne bacheloroppgaven undersøker bærekraftig webdesign ved å undersøke utvikleres bevissthet og praksis, identifisere nåværende utfordringer og hindringer for implementering, og foreslå praksis som bør inkluderes i dedikerte retningslinjer for bærekraftig webdesign. Ved å studere disse aspektene har bacheloroppgaven til hensikt å gi praktiske retningslinjer for bærekraftig nettdesign for å hjelpe interessenter med å prioritere bærekraft i nettløsninger og kollektivt redusere nettets karbonavtrykk. I tillegg vil forskningsresultatene bli presentert på relevante konferanser om Human-Computer Interaction (HCI), og disseminert sammen med retningslinjene på et nettsted utviklet av gruppen.

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1 Introduction

The Internet and the Web have tremendously changed our daily lives, and they continue to shape the way we interact with the world around us through rapid advancements in technology. As a result, it has made communication both faster and more efficient, enabled remote work, made it easier to access information, transformed how we consume entertainment, and revolutionized the shopping experience. However, despite these advancements, there has not been enough focus on the environmental impact they have on the planet. Every activity performed on the Internet, such as visiting a web page, relies on a complex infrastructure that demands significant computational power and electricity [1]. The majority of this energy is derived from fossil fuels, leading to notable emissions of carbon dioxide (CO2) in order to uphold the operation of the Internet [2]. To address this environmental concern, it is crucial to prioritize the reduction of page weight, which refers to the size and resources required to load a web page. Efforts to minimize page weight can lead to a significant reduction in energy consumption, effectively mitigating the environmental impact of the Web.

The development of websites involves a diverse group of stakeholders responsible for the websites' design, development, and maintenance. These stakeholders comprise practitioners, managers, and even customers, among others. It is essential to ensure that all stakeholders are responsible for reducing the carbon footprint of websites, by making them prioritize sustainability in their solutions. This can be achieved through collaboration between industry and academia, ensuring that current and future stakeholders are equipped with the knowledge and tools needed to create sustainable websites. However, it is important to note that knowledge and tools alone may not be enough to effectively integrate sustainability into web solutions. This thesis identified several challenges and barriers that may impede the adoption of sustainable practices by web developers. By recognizing these factors, steps can be taken to overcome them and promote the integration of Sustainable Web Design practices in the industry. In order to address these challenges and barriers, this thesis discusses different approaches, including both top-down and bottom-up strategies.

The Norwegian University of Science and Technology (NTNU) has over the last year increased its focus on implementing sustainability into the university curriculum, and aims to be at the forefront of sustainability and educate responsible practitioners. The problem of how the In-

ternet contributes to the climate crisis has caught the attention of the Department of Design at NTNU Gjøvik. The department recognizes the critical need to find ways to minimize the growing environmental impact of the Internet and has collaborated with us on this thesis to address this issue. This thesis aims to minimize the carbon emissions from the Web by investigating the awareness, practices, challenges, and barriers faced by both industry and academia. By studying these aspects, the thesis seeks to provide practical guidelines for Sustainable Web Design, helping stakeholders prioritize sustainability in web solutions, and as a result, collectively reduce the carbon footprint of the Web.

1.1 Product Owner

The thesis is carried out for Yavuz Inal, on behalf of the Department of Design at NTNU. The department is a part of the Faculty of Architecture and Design and is divided into two branches: one located in Trondheim with a specialization in industrial design, and the other in Gjøvik, which focuses on graphic design and web development. Both branches also specialize in interaction design. The department is made up of more than 50 staff and makes research contributions across various fields, such as health and welfare technology, interplay, and sustainability.

1.2 Problem Statements

This thesis aims to contribute to the reduction of carbon emissions of the Web by raising awareness, expanding available research, and providing guidelines for Sustainable Web Design. This goal emerges from the product owner's objective of reducing the environmental impact of the Internet and improving the curriculum with new tools for the students.

To achieve this, the thesis is divided into three distinct studies: Awareness and Practices, Challenges and Barriers, and Guidelines. Each study respectively addresses the following problem statements:

1. To what degree are developers' awareness and practices regarding Sustainable Web Design?
2. What are the current challenges and barriers to implementing Sustainable Web Design?
3. What are the main practices that should be part of guidelines for Sustainable Web Design?

1.3 Scope

The scope of this thesis has high ambitions, with the goal of developing a holistic approach that results in a set of guidelines to assist stakeholders in creating sustainable websites. However, constraints such as time and the number of project participants must be considered in this regard. To address these constraints and achieve our goal, we have identified the following priorities:

1. **Explore awareness and practices.** Analyze and discuss the data collected by the group in the IDG3101 course, on awareness and practices related to Sustainable Web Design.
2. **Conduct a study on challenges and barriers.** Conduct qualitative interviews with practitioners and prospective practitioners to explore and identify the challenges and barriers they face in relation to implementing Sustainable Web Design practices.
3. **Create guidelines.** Research and identify industry best practices for Sustainable Web Design, and combine them with the insights gained from our two studies to create a comprehensive set of guidelines for all stakeholders regarding the design, development, and hosting of websites.
4. **Disseminate research.** Contribute to the field of Sustainable Web Design by sharing the research findings with the community. We plan to accomplish this goal by presenting the studies, Study 1: Awareness and Practices and Study 2: Challenges and Barriers, at relevant Human-Computer Interaction (HCI) conferences.
5. **Develop and host a website for disseminating guidelines.** We intend to disseminate the Sustainable Web Design Guidelines through a website so that stakeholders can access and integrate them into their design process. This website will be hosted with a professional domain name, to make the comprehensive guidelines for Sustainable Web Design easily accessible to all stakeholders. The website will partially follow WCAG standards during the development process, but it will not be evaluated or discussed in-depth. The website will primarily be designed for desktops, as this fits the use-case scenario.
6. **Conduct user testing of guidelines.** To gather qualitative feedback from stakeholders, comprehensive user testing of the guidelines through a workshop will be conducted. Alternatively, if time constraints exist, it will be replaced by conducting a quantitative study

to obtain user feedback.

1.4 Contributions

The thesis in its entirety contributes to the fight against climate change. Its research aligns with three Sustainable Development Goals by the United Nations: number 10: ”Reduced inequalities”, number 12: ”Responsible consumption and production”, and number 13: ”Climate action”. See the Discussion chapter for further details.

The contributions aim to address the problem statements related to Sustainable Web Design by conducting three distinct studies that examine different aspects of the topic. These studies, in conjunction with the website we created to disseminate the guidelines, provide new and valuable contributions to the field of Sustainable Web Design.

1. **Study 1: Awareness and Practices** investigates the levels of knowledge and implementation of Sustainable Web Design practices among web developers through a quantitative study. The data for this study was collected during the IDG3101 course in the fall of 2022, which was further developed and analyzed as a continuation of this thesis. The results of this study are accepted and will be published by the International Conference on Human-Computer Interaction (HCI International 2023) [3] through Springer by July 2023.

2. **Study 2: Challenges and Barriers** is a qualitative study that seeks to address questions left unanswered by Study 1. Specifically, it aims to identify and examine the various challenges and barriers encountered when implementing Sustainable Web Design practices. This study is submitted for review to the IFIP Conference on Human-Computer Interaction (INTERACT 2023) [4].

3. **Study 3: Guidelines** focuses on the development of Sustainable Web Design Guidelines and seek to reduce the threshold for implementing sustainable websites, by equipping all stakeholders with actionable guidance to help them reduce the environmental impact of their web solutions. The outcome of this study is available on our website sustainableweb.net, and serves as a valuable resource for academia and other stakeholders. It enables academia to integrate the Sustainable Web Design Guidelines into their curriculum and educational materials, and industry professionals to adopt and implement sus-

tainable practices in their work, fostering a collective effort towards a more sustainable web.

1.5 Structure of the Thesis

The thesis is structured as follows, with each of the three distinct studies and the dissemination of guidelines chapter having its own sections for methods, results, and conclusions. The studies and their findings are discussed in their entirety in the dedicated discussion chapter.

The Background chapter provides an overview of the theories and prior research used as the foundation for this bachelor thesis.

The Study 1: Awareness and Practices chapter investigates sustainability awareness and practices in the web development industry through a quantitative study.

The Study 2: Challenges and Barriers chapter identifies challenges and barriers to implementing Sustainable Web Design, and priorities in the development process through a qualitative study.

The Study 3: Guidelines chapter details the development of Sustainable Web Design Guidelines, based on the insight gained from previous studies.

The Dissemination of Guidelines chapter describes the development process of the website that disseminates the guidelines.

The Discussion chapter discusses the thesis and its accompanying research and provides suggestions for future work.

The Conclusion chapter concludes the bachelor thesis by answering its problem statements.

2 Background

This chapter introduces the key concepts, theories, and literature that are relevant to our three main studies. This provides a comprehensive understanding of the research topic, used for further discussions in the Discussion chapter.

2.1 Terminology and Key Concepts

To ensure a shared understanding of key concepts throughout the thesis, we will start by introducing them. We will also explore these concepts in more depth in later sections of this chapter to establish a comprehensive understanding of Sustainable Web Design.

The Web, or World Wide Web, is a virtual space where resources and documents are identified by Uniform Resource Locators (URLs). The documents are linked together using hypertext links and can be accessed via the Internet [5].

Page weight refers to the total size in bytes of a web page. This size is determined by the various resources required for rendering the web page in the browser, including the HTML, CSS, media content such as videos, images, and audio, JavaScript for interactivity, and any third-party assets [6].

Green hosting involves delivering web hosting services with clean energy sources. By doing so, it can reduce or remove the carbon footprint commonly associated with conventional web hosting [7].

Carbon footprint refers to the total amount of carbon dioxide emissions that are produced directly or indirectly by an activity [8], or over the lifespan of a product. Examples of activities include sending an email, driving a car, taking the bus, or heating a home.

Carbon dioxide (CO2) is a colorless and odorless gas that is naturally occurring and emitted from the burning of fossil fuels for energy [9]. It is important to note the significant difference between CO2 and CO2e, where **CO2 equivalent** (CO2e) is a widely used measure to compare the impact of different greenhouse gases on the environment [10]. This includes gases like methane, ozone, and nitrous oxide, which contribute to climate change [11]. Their impact is calculated by comparing them to the global warming potential of CO2. For example, one ton of methane gas has a global warming potential of 25 tons of CO2 emissions [12].

Sustainability is a complex and multi-dimensional concept that is commonly defined as ”fulfilling present needs while preserving the potential needs of future generations” [13]. While sustainability encompasses economic, social, and environmental aspects, our primary focus is on the environmental dimension of sustainability and identifying ways to reduce carbon dioxide (CO2) emissions of websites for the sake of preserving the environment. The approach to accomplish this is defined as **Sustainable Web Design**, a method of designing websites that are environmentally friendly and beneficial to humans. Sustainable Web Design places great importance on minimizing the environmental impact of web services, with an emphasis on reducing carbon emissions and energy consumption. The ultimate goal of Sustainable Web Design is to promote a more sustainable digital ecosystem by prioritizing the planet's health [14]. We use this term to refer to both the visual design and the coding aspect of developing a website. The United Nations and Defining Sustainability section describes how the United Nations defines sustainability and its pillars.

Web Accessibility is a practice that ensures inclusive and accessible web solutions for everyone. It is both an ethical and moral responsibility that allows users with diverse abilities and resources to access web services unhindered. Examples of making websites more accessible to users with visual- or hearing impairments are including alternative text to images, and adding captions or transcripts to audio and video content.

Web Content Accessibility Guidelines (WCAG) are a set of official guidelines ensuring accessible web solutions to people regardless of their disabilities. These include visual impairment, auditory, physical, speech, cognitive, and neurological disabilities. To achieve an accessible web, these guidelines are based on four main principles: perceivable, operable, understandable, and robust [15]. Throughout this thesis, we will refer to these guidelines using the abbreviated term WCAG.

Sustainable Web Design Guidelines (Sustainable Web DesignG) refers to the product developed as part of the third study of this thesis. Sustainable Web DesignG aims to promote Sustainable Web Design practices that reduce the carbon footprint of websites. These guidelines provide specific strategies and best practices that web designers and developers can implement to lower energy consumption and carbon emissions from their web solutions. The abbreviated term Sustainable Web DesignG will be used throughout this thesis to refer to these guidelines.

2.2 Brief History and Current Statistics of the Internet

In 1990, Sir Tim Berners-Lee wrote the three fundamental technologies that remain the foundation of the Internet and the World Wide Web (the Web) as we know it today, namely HTML[1], URI[2], and HTTP[3] [16]. The first website was served on the open Internet by the end of 1990, and in 1991, people not affiliated with CERN[4] were invited to join this new web community. Already by the end of 1994, more than 10 000 web servers were accessible around the world, with a user base that had quickly grown to 10 million users [17]. This was the beginning of a new digital era, where the flow of information, content, and new ideas gave rise to new approaches in fields such as information, politics, scientific research, education, and culture. This societal transformation is commonly referred to as the ”information society” [18].

The impact of the Internet and the Web on societies, cultures, and the way we interact with each other has grown rapidly ever since their debut almost 30 years ago. The world's population surpassed 8 billion people in November 2022 and is continuing to grow steadily in 2023 [19]. As a result, the number of Internet users has also grown significantly. According to Datareportal [20], there were 5.16 billion Internet users in the world as of early 2023, representing 64.4% of the total global population. This number has been steadily increasing, with 168 million new users added in the past year alone. Additionally, there were 5.44 billion unique mobile phone users in the world as of early 2023, accounting for 68% of the population [20]. The downside of this rapid growth of Internet consumption is the amount of carbon emissions produced by the Internet [1]. On average, each Internet user spends over six and a half hours online daily [20], leading to increased energy consumption and environmental pollution, as discussed further in the following section.

2.3 The Environmental Cost of the Internet

The Internet has become an essential part of our daily lives, by giving us access to an incredible amount of information at our fingertips at any time. However, this convenience comes at a considerable cost that many might be unaware of. The Internet requires significant amounts of computing power, both from the devices in our hands and the vast server farms hidden away in

[1] HyperText Markup Language: Denotes the structure and content of a web page
[2] Uniform Resource Identifier: Link to a specific resource
[3] Hypertext Transfer Protocol: The data communication protocol the Web is served over
[4] A European organization for nuclear research

the ”cloud”. Each computing task requires energy, and most of today’s energy is generated by burning non-renewable carbon fuels. Although the Internet may seem intangible, it is actually made up of data stored on physical servers and infrastructure that require vast amounts of energy to store and process. This is done in data centers composed of multiple servers located across the globe that operate continuously, all year round. According to a post in the New York Times from 2012 [21], data centers use about 30 billion watts of electricity, about the same as 30 nuclear power plants. This means that a single data center can consume as much electricity as a small village.

Engaging in online activities like streaming videos, playing online games, or browsing social media may not seem like they have any environmental impact, but in reality, they generate significant amounts of carbon emissions [22]. For instance, streaming a generic video online emits around 100 grams of CO2 equivalent per hour [23]. Even seemingly trivial online activities, such as sending an email, cannot be ignored in this context. An average email alone can generate around four grams of CO2e, and this number jumps to 50 grams of CO2e for an email with an attachment. Even simply receiving a single spam email emits 0.3 grams of CO2e. As per Statista [1], approximately half of all emails are spam, resulting in around 55 trillion spam emails sent annually. The combined effect of these emissions is staggering, with spam emails alone producing around 16 million tons of CO2 emissions per year.

Browsing the Web contributes to environmental pollution, with the number of resources on a website and the high amount of global website visitors being the major contributing factor. According to the HTTParchive, the median web page size has increased by over 50% in the past six years [24]. In 2018, the carbon footprint and environmental pollution from the Internet were so significant that if it were a country it would have ranked as the sixth highest-polluting country in the world [25]. Alarmingly, it is expected to worsen, with the Internet projected to become the fourth most polluting country by 2025 [26]. As of April 2023, the median page size for desktop websites was 2.36MB and just over 2MB for mobile websites [24]. According to HTTPArchive [6], images are the primary contributor to the weight of a web page. As of April 1st, 2023, the median size of images on an average website was approximately 1003.5KB of data, making up approximately half of the total page weight [24]. To put this into perspective, every gigabyte of data transmitted over the Internet produces 4.2g of CO2, according to calculations by McGovern [1]. Therefore, a single desktop web page of 2.36MB would at the very least produce approximately 0.0099g of CO2 each time someone visits the page. If half of the page weight is

made up of images, it means that the average website's images alone would be responsible for emitting a minimum of 0.0049g of CO2 per page.

The cumulative impact of billions of these actions taking place each day on a global scale is noticeable. In 2023, it's estimated that around 328.77 million terabytes of data will be generated worldwide, with projections suggesting this will increase to 181 zettabytes by 2025 [27]. To put this into perspective, 90% of the world's data has been generated in just the past two years. As such, it is important to be mindful of our online activities and the impact they have on the environment.

To measure a web page's impact, specifically its weight, developers can use the built-in developer tools in modern web browsers (see Figure 1). These tools provide among other things an overview of the resources that are downloaded and pulled from the local cache when accessing a website. You may generate a website performance report using Google's Lighthouse, an open-source page metric tool (see Figure 2). This tool evaluates a website's performance, alerts developers of any potential issues, and guides them on how to address these issues. It is essential for a developer to understand and utilize these tools to ensure the efficient use of resources and optimize the website's performance. This ensures the web solution runs smoothly, even on less powerful devices and connections.

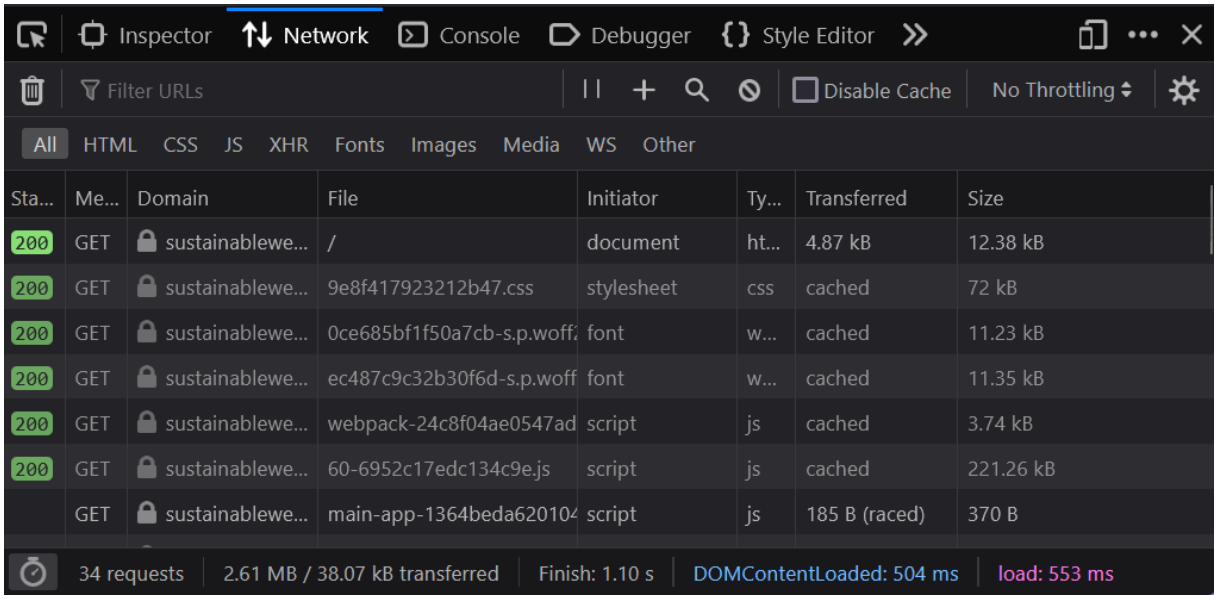

Figure 1: An example of the network tab in Firefox's web developer tools suite, showing all the resources loaded, the total size both downloaded and cached, and the time it took to render the website.

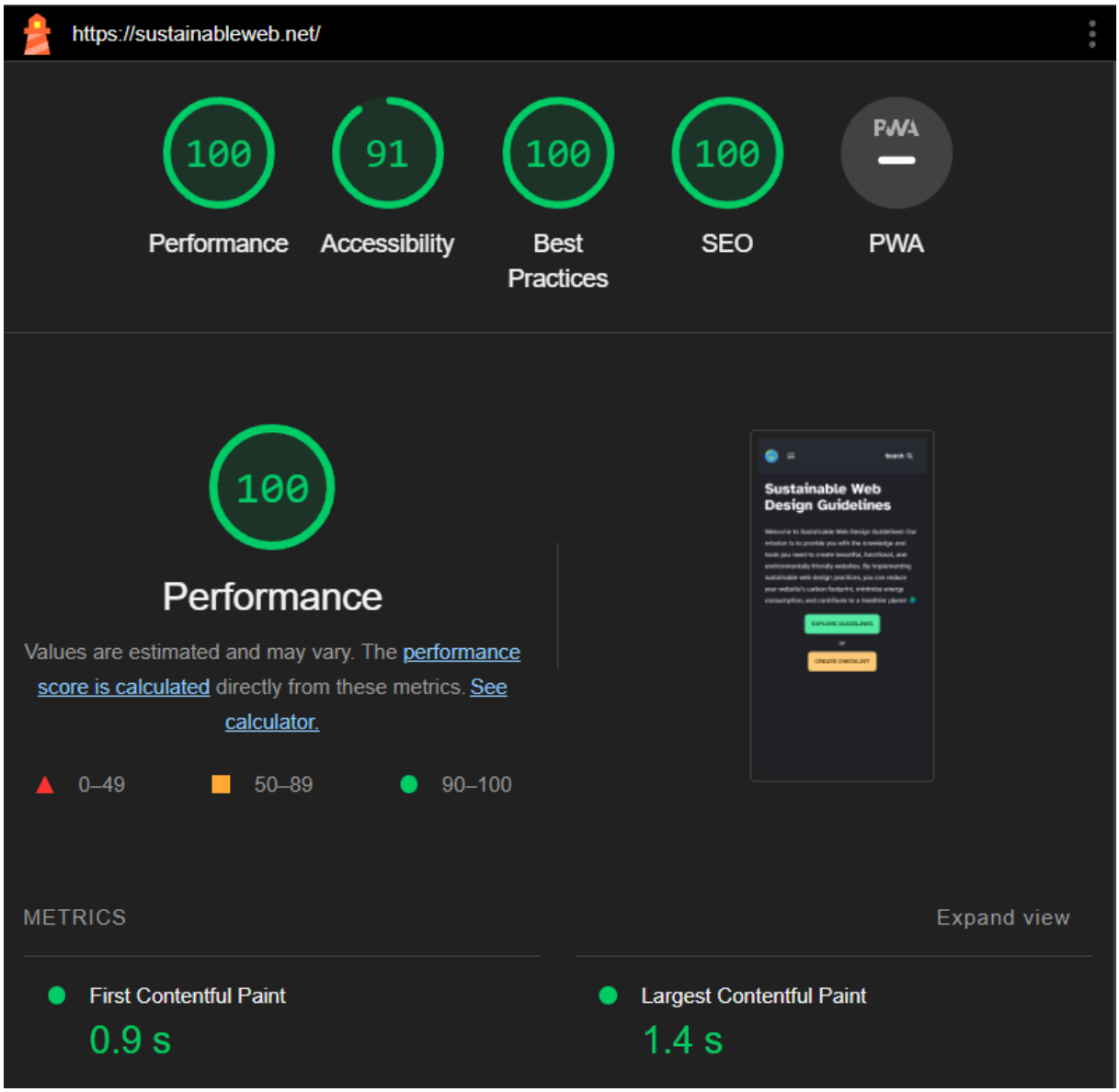

Figure 2: An example of what a Lighthouse report looks like.

2.4 United Nations and Defining Sustainability

United Nations, an international organization founded in 1945 [28], is working towards a sustainable future through the implementation of their 17 Sustainable Development Goals [29]. Sustainability is commonly divided into three dimensions, often referred to as the three pillars of sustainability: social-, economic- and environmental sustainability (see Figure 3). Each pillar has its focus, yet they are interdependent and need to be addressed in an integrated manner.

Figure 3: The three pillars of sustainability, along with corresponding UN Goals. (Illustration by [30])

While the three pillars of sustainability do not have any academic definition [31], the Brundtland Report concludes with specific needs that fit the three pillars [32]. Social sustainability refers to a society's capacity to sustain social connections, satisfy fundamental human requirements, and establish habitable environments for all members of the population. This encompasses education, healthcare, food access as well as other essential elements of living. Moreover, it deals with concerns such as fairness and civil rights, cultural multiplicity, and communal expansion. Economic sustainability refers to the ability of an economy to generate value and promote economic growth. This means that economic activities should be conducted in a manner that is environmentally friendly and socially responsible to ensure the sustainability of the resources used in production, as well as the long-term prosperity of businesses, communities, and individuals. Environmental sustainability refers to a balance between human activities and natural resources. This balance ensures that current and future generations can benefit from natural resources without depleting them, causing irreversible damage, or jeopardizing the ability of the environment to regenerate.

Over time, there has been a significant increase in the attention given to sustainability and related knowledge. To measure this trend, a search tool provided by Springer [33] was used to compare the number of publications containing the word "Sustainability" each year and calculate the Average Growth Rate (AGR). In 2019, Springer published 29,651 documents, whereas in 2022 they released 52,571 documents, indicating a growth rate of roughly 77.29% between those two

years.

2.5 Sustainable Web Design

This section delves deeper into the field of Sustainable Web Design by explaining its core concepts and presenting a literature review.

2.5.1 Carbon Emission Tools

The sustainability of a web page is closely tied to its page weight, as higher page weight contributes to decreased sustainability and increased CO2 emissions. To measure the CO2 emissions of web pages, two primary tools have emerged: Ecograder and Website Carbon Calculator. These tools allow users to input a URL, which is then analyzed to estimate the amount of CO2 emissions generated with each visit to that particular web page. However, it is important to acknowledge that accurately measuring carbon emissions from the Web presents significant challenges, and these tools have certain limitations.

Ecograder is a tool created by MightyBytes with the purpose of identifying tasks that will improve the sustainability of the websites being tested. It utilizes ”CO2.js”, a library created by The Green Web Foundation, which estimates the CO2 emissions associated with digital activities, and Google’s Lighthouse [34]. The CO2.js library estimates emissions by using two carbon estimation models: The OneByte model, and the Sustainable Web Design model [35].

Similarly to Ecograder, the Website Carbon Calculator, developed by Wholegrain Digital, is a tool created to estimate websites’ carbon emissions. The calculator uses various data sources and algorithms to estimate a website’s carbon footprint, including the energy consumption of servers and the devices used to access it. It takes into consideration the location of the servers, and the hosting provider’s energy type [36]. The calculator also offers practical recommendations, such as optimizing media files, reducing third-party scripts, and choosing a sustainable hosting provider.

Although these tools are valuable in estimating carbon emissions, they cannot provide precise measurements. This is because they only offer estimates of website emission rates and rely exclusively on available data. As a result, these tools do not conduct any internal checks on the server hosting the website. This means that they can only make assumptions based on visible

aspects of the host and website, such as the hosting provider, the utilization of green energy by the hosting provider, the source of the website's resource loading, and other similar factors.

2.5.2 Defining Web Design

Web design is the process of designing websites that are accessed on the Internet [37]. The term can cover both the user experience and the development process of websites but usually refers to the user experience. However, in our case, we use the term for unifying both processes, as websites need to be both designed and developed with sustainability in mind. The components of web design consist of various elements such as typography, multimedia, graphics, images, color scheme, and layout. It is essential to use these components in a way that reflects the brand identity while providing an optimized user experience. Web design also includes concerns regarding user-friendliness and accessibility. The information presented should be clear, concise, and easily accessible with an intuitive design that provides search engine optimization techniques. This involves optimizing it for mobile devices along with including features such as responsive designs, effective navigation menus, and calls-to-action. The Web Content Accessibility Guidelines [15] created by W3C are aimed at helping with this.

2.5.3 Connecting Sustainability with Web Design

When connecting sustainability with web design, we refer to a design approach that aims to minimize the environmental impact of websites. One definition of Sustainable Web Design is "an approach to designing web services that prioritize the health of our home planet. At its core is focusing on reducing carbon emissions and energy consumption" [14, p.5]. Due to the carbon emissions of every action and presence online, it is important to reduce the overall energy consumption of websites. To achieve this, adopting Sustainable Web Design strategies that reduce page weight is crucial. This is because a heavier web page results in increased energy consumption and carbon emissions.

To minimize overall page weight, websites must be designed to thoughtfully incorporate images, fonts, videos, and colors, according to the suggested practices by Greenwood [14]. Some practices involve utilizing darker colors for OLED screens and avoiding the use of external fonts. Employing reusable code and modularity also enhances efficiency. But it is important to notice that on a typical website, images and videos are the ones responsible for most of the data transfer, with pictures being the primary cause of carbon emissions. Assessing whether

each resource, such as an image, video, or external font, is truly essential to include as part of a web design is critical since they all consume electricity and bandwidth. This evaluation process is important to ensure minimalism and to lower the carbon footprint. While the idea of minimalism might indicate that we should avoid the use of external files completely, Sustainable Web Design should not be a limiting factor. Instead, it should guide designers toward creating environmentally-friendly websites based on the goals of the users. By assessing file formats and sizes, we can better understand technology's impact on the environment and choose the most sustainable options. The amount of storage and bandwidth required for different file types could greatly affect a website's overall environmental footprint, so it is therefore recommended to stay up to date on newer and more efficient formats.

Sustainable Web Design offers several benefits, both for the environment, accessibility, and businesses [38, 39]. One calculation stated that an average website generates approximately 4500 pounds (approximately 2 041 kilos) of carbon dioxide every year, which is equal to covering more than 10 000 miles (approximately 16 000 kilometers) with the average new car [40]. The reason behind this is attributed to websites having numerous pages, along with images that are excessively large, and not utilizing hosting practices efficiently. By applying Sustainable Web Design and converting to green hosting, the overall impact of websites can be dramatically decreased. Another important aspect that Sustainable Web Design touches on is web accessibility. According to the World Health Organization, around 16% of the world's population experiences a type of disability [41]. In order to make sure that websites are accessible to as many as possible, following WCAG is a good start. It will increase inclusion and sustainability, as doing measurements for web accessibility often reduces page sizes, or the amount of data transferred [42]. Designing sustainable and accessible websites can also benefit businesses by enhancing website performance, which would lead to faster loading times and increased user satisfaction. This may result in higher customer retention rates and decreased bounce rates. Additionally, a reduction of web pages needed for completing tasks results in less electricity consumption [38], and less hosting and development costs [39].

2.5.4 Literature on Sustainable Design and Development

This thesis is inspired by the concepts and principles presented in three influential books regarding sustainable design and the environmental impact of the Internet. Tim Frick's "Designing for Sustainability: A Guide to Building Greener Digital Products and Services" (2016) [12], Gerry

McGovern's "World Wide Waste" (2020) [1], and Tom Greenwood's "Sustainable Web Design" (2021) [14], provided valuable insights that informed the development of this thesis' three studies. These books highlight the importance of sustainable design within the ICT industry and offer practical solutions for reducing its environmental impact.

Frick and Greenwood's combined insights offer a well-rounded understanding of Sustainable Web Design and development, giving designers and developers valuable insights into how to create more sustainable and accessible solutions. Frick introduces a variety of design approaches aimed at enhancing sustainability within the industry. His main contribution is raising awareness of the need for web sustainability and providing the knowledge necessary to develop sustainable digital solutions through a suggested framework. The framework is organized into four categories [12, p.56]:

- More sustainable components, including green hosting
- Findability, content strategy, and SEO
- Design and user experience
- Web performance optimization (WPO)

By embracing these topics, the performance of web pages, navigation, and the likelihood of locating the appropriate web page will be enhanced, while also improving accessibility and ultimately reducing the environmental impact. Our primary focus within the framework is on design, which takes into account the entire life cycle of products and services, emphasizing long-term needs over short-term user demands. Some best practices include carefully implementing colors, typography, and images to minimize page weight and energy consumption. Greenwood proposes similar practices and elaborates on these topics, offering a comprehensive guide to creating energy-efficient and environmentally-conscious websites. Generally, Greenwood delves deeper into the various design elements of a web page. For instance, he recommends several strategies to decrease image file sizes, such as selecting the right file format, adjusting compression levels, applying blurs to photos, and utilizing scalable vector graphics (SVG). Moreover, Greenwood introduces development techniques beyond the scope of Frick's contribution, including code compression and blocking web traffic from malicious bots.

Unlike the previously mentioned authors, McGovern's focus is not solely on design and development. He acknowledges the impact of web design elements such as images and typography

on page weight, but his main contribution is bringing attention to the commonly overlooked environmental consequences of our digital world, especially in regard to the Internet's significant carbon footprint. By presenting scientific and analytic data, he highlights how increasing demand for digital solutions harms the environment and emphasizes the need for sustainable digital practices like reducing data storage, minimizing resource-intensive applications, and employing energy-efficient web design principles. His work offers practical advice for individuals and organizations to reduce their digital waste while making environmentally responsible choices online. One of the pieces of advice is encouraging people and businesses to be more conscious of the emails they send, receive, and store to aid in reducing digital waste. This can be achieved by decreasing the storage space needed for large email accounts, therefore saving energy. Additionally, selecting web hosting providers who prioritize eco-friendly practices like using renewable energy sources or investing in efficient hardware may also contribute towards this goal.

Although there is limited research specifically focused on Sustainable Web Design, there are some studies available on sustainable software development, a related field that overlaps with the development aspect of web design. An interview study with research software engineers [43] found that the sustainability of software is dependent on a combination of intrinsic and extrinsic factors. Intrinsic factors include elements like standardized, modular, useful, well-documented, and testable code that can be easily scaled and read. The participants placed importance on testing the software for functionality as well as using libraries with standardization to ensure future-proofing. Some of their results align well with another study [44], which also found that documentation and testing are important parts of implementing sustainability within software development.

Another result by [44] was that it is crucial to incorporate sustainable practices throughout the entire development process and involve all stakeholders, including practitioners, managers, governments, and customers, to ensure sustainability. Although Study 1: Awareness and Practices has shown that stakeholders in web design are knowledgeable about some sustainable practices for the web, they do not implement them. Studies conducted within the software industry have revealed limited knowledge of green and sustainable practices among software practitioners [45, 46], which is because the majority of practitioners focus their perception on sustainable software specifically in terms of reusing source code or not having in-depth knowledge of sustainable practices during development. But there is also a study that found awareness of such practices along with successful implementation [47], where the participants knew how to create

sustainable software that minimizes energy usage and mitigates the environmental harm caused by its operation.

To the best of our knowledge, there are no publicly released guidelines for Sustainable Web Design, and there is only one suggestion for sustainable software guidelines. This suggestion focuses on a complete aspect, including system design, development, operation, and maintenance [48]. Their guidelines consist of specific approaches, methods, and tools in software engineering that promote sustainability, which was successfully validated through a case study. Even though their guidelines are not directly applicable to Sustainable Web Design, they present some valuable lessons from their application of the guidelines. One interesting lesson was that to implement sustainable software engineering, it is essential to provide straightforward guidelines. Simplifying the instructions and presenting them in a practical format could help lower barriers to the adoption of sustainability-focused software engineering methods. Another valuable lesson was that sustainable development practices could be disregarded due to time and budget constraints, along with insufficient enforcement and motivation. It is imperative to compare the implementation of web accessibility and web sustainability as we can draw valuable lessons from the challenges faced in web accessibility when addressing Sustainable Web Design. By doing so, we can create web solutions that not only meet the needs of a variety of users but also minimize the impact on the environment.

Numerous countries require adherence to the Web Content Accessibility Guidelines (WCAG) to increase accessibility and inclusion in society [49], but research has consistently shown that developers have different levels of awareness and understanding of accessibility requirements [50, 51, 52]. Furthermore, there exists a relatively low level of adherence among developers to accessibility guidelines due to insufficient awareness [53, 54, 55]. Consequently, individuals with disabilities and elderly populations may encounter websites that are either partially or entirely inaccessible [56, 54, 57, 58, 59, 60, 61]. This further results in inequality of access to information to those with special needs, and influences the social sustainability [62]. Some of the challenges for web accessibility include adhering to established standards and guidelines, enhancing user consciousness through education, and evaluating performance using automated tools as well as user testing [63]. The field of Sustainable Web Design lacks well-established guidelines and standards for developers to implement sustainability practices when designing web solutions. It is, therefore, beneficial to comprehend the challenges faced in web accessibility in order to identify potential issues that may arise during the development and usage of

guidelines for Sustainable Web Design.

While a few attempts to provide recommendations to guide developers toward a more sustainable design approach has been made by the sustainability advocates Greenwood [14] and Frick [12], scant attention has been paid to how web developers view and practice sustainability in their web projects. While Sustainable Web Design is a relatively new and less established field compared to web accessibility, there is a chance to establish it as a regulated and recognized component of web development. Regardless of the current challenges being faced in web accessibility, the impact of regulations on compliance with guidelines has been shown in the case of web accessibility to have positive outcomes [54]. Therefore we see an opportunity to establish Sustainable Web Design as a recognized and regulated component of web development, similar to WCAG. The development of Sustainable Web Design guidelines and regulations is critical to ensuring that developers prioritize sustainable design practices. By establishing Sustainable Web Design practices as a recognized component of web development, we can work towards a more accessible and sustainable web.

2.5.5 Advocates of Sustainable Web

This section aims to provide an overview of existing resources pertaining to Sustainable Web Design from external advocates of Sustainable Web. Specifically, it focuses on companies and organizations that actively promote sustainable practices or guidelines. Through a critical evaluation of these resources, we identify their strengths and weaknesses, highlight key similarities and differences, and explore their potential to inform Sustainable Web Design practices.

Mightybytes was started by its founder and current president Tim Frick in 1998. Mightybytes as a company is committed to sustainability, with a philosophy supporting people and the planet, and sharing prosperity. As a business, Mightybytes work as a consulting firm, that provides digital sustainability services, that aim to reduce the client's digital environmental impact. This service works in four key areas, improving performance, usability, findability, and green hosting. Mightybytes promote sustainability through Sustainable Web Design and raise awareness of the Internet's massive environmental impact. [64] Tim Frick is the author of Designing for Sustainability: A Guide to Building Greener Digital Products and Services [12]. Mightybytes also created a free online tool called Ecograder. This tool allows users to enter a URL into its system, which accurately reports the performance and climate impact of the given website

URL, including page emissions and page weight. This tool aims to help people understand the environmental impact of digital products and services and gives methods and ways to reduce consumption, eliminate waste and use less energy. Mightybytes is also a certified B Corp member and co-founded B Local Illinois [64].

Wholegrain Digital was founded in 2007 by Tom Greenwood and his wife, Vineeta Greenwood, with the aim of helping organizations succeed online. They focus on sustainability and have become an industry-leading company in web sustainability and performance, promoting the industry towards a zero-carbon future. The goals of Wholegrain Digital are to exceed net zero by the end of 2023, ensure the average CO2 emission of their websites is less than the industry average, and increase hosting powered by renewable resources, reaching 100% by 2026. Tom Greenwood is also the author of Sustainable Web Design, a book published by A Book Apart, that promotes sustainable methods and awareness.

In comparison to our work in this bachelor thesis, there are similarities in prioritization to promote and spread awareness about sustainability within web development and design. However, neither of the companies mentioned has a resource dedicated to promoting sustainable development methods similar to what we see as necessary for improving the industry's development processes. In fact, after researching online there seems to be only a single direct competitor that is currently developing a similar product and resource that we aim to create. This competitor is called Sustyweb [65].

Sustyweb is the shortened version of the W3C Sustainable Web Design Community Group, which is dedicated to creating sustainable websites. According to their public website, the mission of the group is to create guidelines, tools, and resources for web and digital professionals to incorporate environmental sustainability and related principles into their processes and practices. The primary responsibility of the group is to create environmental guidelines, to be used by digital professionals and academia. This group is administered by Tim Frick and Alexander Dawson. Based on the information that is publicly available, they are working on a guideline, which is compromised of different committees. These committees are UX Design, Web Development, Hosting, infrastructure and systems, analytics, measurement and reporting, Business strategy, and Product management. The problem here is that the progress and actual guidelines they are working on are currently not available to the open public, as there is a procedure to join an online Slack Group, so there is not much more information as to how far or much progress

has been made in creating their guideline.

In conclusion, there are no publicly available guidelines that aim to promote, educate and spread awareness about sustainable web development and design. Therefore, we can state that there is a lack of existing digital solutions that describe or accomplish all the problem statements of our bachelor thesis. Since the awareness and need for sustainable solutions to lessen the environmental impact of the industry is critical to ensure sustainability, we can defend the necessity of creating a resource, to further the research in sustainability within the Internet.

3 Study 1: Awareness and Practices

To address the first research question, ”*To what degree are developers' awareness and practices regarding Sustainable Web Design?*”, a quantitative study was conducted. This study aimed to explore and compare the extent to which sustainable development practices are understood and applied by these developers. The results of this study provide insights into the current state of Sustainable Web Design practices in the industry and identify areas where further improvements can be made. This study collected data from 77 participants, representing practitioners in the Norwegian web industry and prospective practitioners. The development methods focused on in this study are optimization of media formats, compression, color usage, and font subsetting. This study has been accepted as a conference paper at the HCI conference and is being published in July 2023.

3.1 Methods

We conducted an anonymous, online questionnaire in Norwegian to explore the awareness and practices among developers and undergraduate students. The questionnaire was conducted over a period of three weeks between November and December 2022, where most of the data originated from web developers working in the Norwegian web industry. The questionnaire consisted of 33 questions, split into three sections (see Appendix A for all the questions included). These questions were devised with ”Sustainable Web Design” [14] and ”Designing for Sustainability” [12] in mind. The three sections were:

1. **Demographic:** Gathered information about the participants, such as job titles, work experience, company size, and education.
2. **Practices:** Explored the participants' methods and techniques, regarding Sustainable Web Design, in their development processes.
3. **Awareness:** Measured the participants' knowledge of Sustainable Web Design and its relevance.

3.1.1 Demographics

With a total of 77 respondents who completed the questionnaire, most participants were web professionals, as in practitioners, who currently worked for a company within the Norwegian web industry. When asked about their current roles, the majority (55.8%, n=43) were full-stack developers, 15.6% (n=12) of participants were front-end developers, 9.1% (n=7) of participants were designers, 5.2% (n=4) worked as management, 1.3% (n=1) had the role as DevOps, 5.2% (n=4) as back-end or computer engineer, and the remaining 7.8% (n=6) were students. In total, 71 participants were practitioners representing the industry, and 6 participants were prospective practitioners representing students. When asked about their work experience, the most frequent answer from the participants (35.2%, n=25) was between two and five years of experience. 25.4% (n=18) of participants had between 10 and 20 years of experience, 14.1% (n=10) had between one and two years of experience, 12.7% (n=9) had between five and ten years of experience, and 4.2% (n=3) had more than 20 years of experience in the industry. The remaining six participants (8.5%) had less than a year of work experience in the field.

In regard to age groups, the majority (50.6%, n=39) of participants were in the age group between 25 and 34, 26% (n=20) were between 35 and 44, 15.6% (n=12) were between 18 and 24, and the remaining participants (7.8%, n=6) were between 45 and 55 years old. Concerning their educational background, 38 participants (49.4%) had a master's degree, 23 (29.9%) had a bachelor's degree, and the remaining participants had graduated either high school (18.2%, n=14) or vocational school (2.6%, n=2). Most participants (76.2%, n=48) graduated from the field of web development, or computer science (12.7%, n=8). Other fields reported by participants were education in tourism and management, music, and natural science.

3.1.2 Practices

The practices section of the questionnaire aimed to gather insight into the practices, methods, and techniques related to Sustainable Web Design used by practitioners in their development process. The categories of these questions were mostly focused on web design and front-end development practices, consisting of questions related to images, fonts, compression, videos, colors, and reusable code. This data was gathered to be analyzed and compared later to their awareness measured later in the questionnaire. It was important to question their development practices before measuring the awareness level, to not influence the participants' answers when

measuring their personal practices.

3.1.3 Awareness

The awareness section aimed to measure the participants' knowledge and understanding of Sustainable Web Design and its importance. These questions were focused on carbon emissions and the energy efficiency of different development practices in the web industry. These development practices focused on the same categories as the practices section. In this section, the correct answers refer to the most sustainable option in the questions given to the participants.

3.1.4 Comparing the Efficiency of Media Files

In our study, we conducted a comparison between a rasterized and a vectorized image in order to determine which file format would be more sustainable. Typically, logos are vectorized while regular photos are rasterized. We used two separate software tools, ImageMagick and Adobe Illustrator, to change the image format. ImageMagick is free software that helps with viewing, modifying, and changing image files. We also used Adobe Illustrator to export the vector image using the default settings. The original size of the rasterized image was 24.704KB in the ARW format. In contrast, the vectorized image was much smaller at only 13.7KB in the SVG format. To facilitate the comparison of the two formats, we scaled both images to a similar range of sizes (0-100K), with the maximum scale value representing the largest file size from each image comparison. This enabled us to plot both comparisons on the same graph despite the differences in size.

To measure the differences in the final file size of each video codec, we utilized FFmpeg, a suite of tools used to manipulate and edit various forms of multimedia content, including video, audio, and subtitles. We used fast presets (”8” for AV1 and ”fast” for H264/H265) and the highest possible CRF value (“63” for AV1 and “51” for H264/H265) when transcoding the video files into MP4 containers. MP4 was selected as the baseline format for the comparison due to its popularity, as revealed in the questionnaire. Additionally, MP4 is an efficient format with accessibility features such as audio description tracks and captioning [14].

3.2 Results

The results section of this study presents the analyzed data and results from the questionnaire and our research from comparisons of media formats. This section starts with the results from our media format comparisons, followed by the analyzed data from the participants' practices, and finally the comparisons of participants' awareness and practices.

3.2.1 Comparison of Media Format Efficiency

This section explains the results from our tests and comparisons for image format and video codec, aimed to verify the sustainability of each format.

Image. The file size differences between image formats are substantial, as seen when comparing a 250x50px logo rasterized from an SVG to a 6000x3376px photo taken with a camera in various formats. While the logo ranges from 1.76KB (AVIF) to 673KB (EPS), the camera image ranges from 480KB (AVIF) to 138MB (TIFF). It is worth noting that the AVIF format's compression seems to smooth out some colors, which is only noticeable when zooming in, and in such cases, it appears better when zoomed out than the grainy colors of TIFF. Although AVIF is the smallest file format, vector images offer additional advantages in design. The questionnaire revealed that PNG and JPEG are popular for displaying pictures, but their file sizes are significantly larger than AVIF, which is 70 times smaller than JPEG and almost 100 times smaller than PNG. The participants favored SVG, PNG, and JPEG, while EPS and APNG were less popular. The AVIF format produced the smallest file size for the logo, while EPS produced the largest. In Figure 4, the x-axis displays file sizes of various image formats in kilobytes (scaled between 0-100K), and the y-axis represents the average Likert scale response, multiplied by the number of responses, ranging from ”Never” to ”Always.”

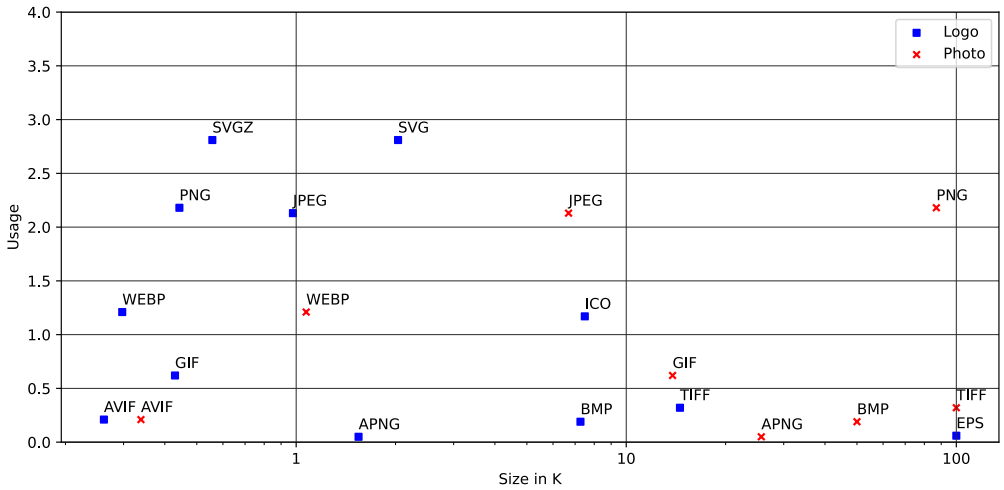

Figure 4: Scatterplot Chart comparing the size and usage of different image formats.

Video. In the study, it was found that 67.6% (n=52) of the participants reported using videos on their websites, with 80.8% (n=42) of them using the MP4 video container format. To gain deeper insights into the relationship between videos and data savings, the study also investigated the various video codecs supported by this container format, namely H264, H265, and AV1. Starting out with an original file size of 64.7MB, all the resulting video files were reduced to 1.1MB in size. This shows that file sizes rather correlate with bitrate than file extension. Both H264 and H265 require a higher bitrate to match the visual quality of AV1. This results in a larger file size.

Figure 5: Comparison of visual quality when transcoded with different video codecs

Figure 5 highlights the varying video codecs and the corresponding visual quality when transcoding each codec to the same file size. File formats are shown to have a negligible effect on file sizes when transcoding with the same codec. In prior research conducted by Greenwood [14], the file format was hinted towards being the primary factor in achieving size reductions. Greenwood revealed that they were able to reduce the video file size by converting from WEBM to MP4. However, our research reveals a more nuanced relationship between the file format and size. It is the codec that primarily determines the file size, rather than the file format itself. For instance, when transcoded with the AV1 codec, the difference in file size between MP4 and AVI is minimal (0.09MB), while still maintaining the same visual quality.

3.2.2 Practices

When asked how much participants write and use reusable code, the majority (61%, n=47) answered ”Often”, while 20.8% (n=16) of participants reported ”Always”. Additionally, there was 13% (n=10) of participants reported to write reusable code ”Sometimes”. The remaining participants were equally split, where 2.6% (n=2) reported they ”Rarely” write reusable code, while the last 2.6 (n=2) ”Never” do it. After analyzing the results, it can be indicated that a significant portion of participants prioritizes writing reusable code, as a common practice in their development process.

According to [14], the color black is the most energy-efficient on modern OLED screens, while white is the most energy-consuming. As a result, using darker colors on a website or providing a dark mode option to users can be beneficial. When asked how often participants offer users both dark and light mode, the results of the study indicate that only a small percentage (1.3%, n=1) of the participants ”Always” offer this to their users, while 7.8% (n=6) reported offering it ”Often”. Moreover, 20.8% (n=16) stated that they offer the feature ”Sometimes”, and 37.7% (n=29) responded ”Rarely”. In contrast, 32.5% (n=25) of the participants reported ”Never” offering the feature. These results suggest that the majority of developers (approximately 70%) do not frequently prioritize the inclusion of a dark and light mode feature.

Typography. For the questions regarding the use of external fonts, the majority (44.2%, n=34) of participants answered that they ”Often” use external fonts. 16.9% (n=13) of participants reported they ”Always” use it, while 19.5% (n=15) use external fonts ”Sometimes”, 14.3% (n=11) use it ”Seldom” while the remaining four participants (5.2%) ”Never” use external fonts. However, the majority (83.1%, n=64) of the total participants responded negatively when asked about their familiarity with and use of font subsetting, meaning they do not optimize their fonts adequately. After analyzing the data, we saw that only 16.4% (n=12) of participants who use external fonts were both familiar with and used font subsetting, while 61.8% (n=8) of the participants who ”Always” use external fonts and 91% of participants who ”Often” use external fonts were not familiar with font subsetting, meaning there is a serious lack of knowledge in this specific context.

Compression. The majority of participants commonly compressed images (62.4%, n=48), videos (46.8%, n=36), and code (61%, n=47), while sound files (58.5%, n=45) and software (52%, n=40) were compressed less frequently. Of the participants who reported regularly using external fonts (61%, n=47), a significant portion answered that they ”Never” compress them (29.8%, n=14), while others answered doing so ”Rarely” (23.4%, n=11).

3.2.3 Awareness

In the first question of the awareness section, the participants were shown two pictures of the same website, where the first had a dark color theme and the other had a white color theme (see Figure 6). Here, they were asked to choose which website they believed was the most energy efficient on modern mobile phones. Almost all participants (94%, n=72) answered correctly that

the dark-themed website was the most efficient.

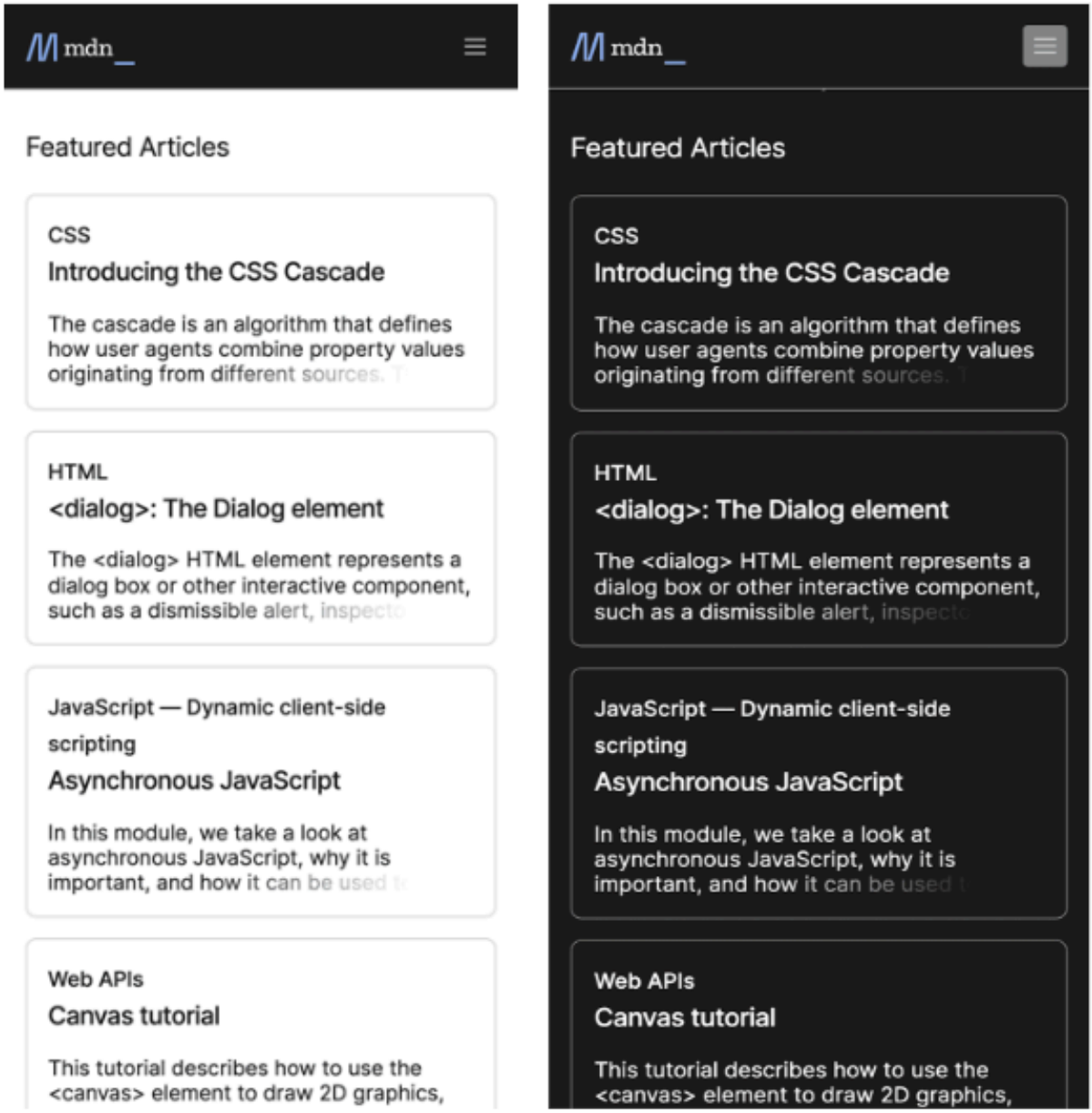

Figure 6: MDN website in white and dark color themes.

The next question was similarly structured, where the participants were shown four alternatives for the same website. The first alternative had a colored picture covering the whole page, the second alternative had a monochrome picture covering half the page, the third had a colored picture covering half the page and the last alternative was a web page with only text. Here the participants were to identify the most sustainable alternative, where a majority (82%, n=63) answered correctly, by choosing the text-only website as the most sustainable alternative.

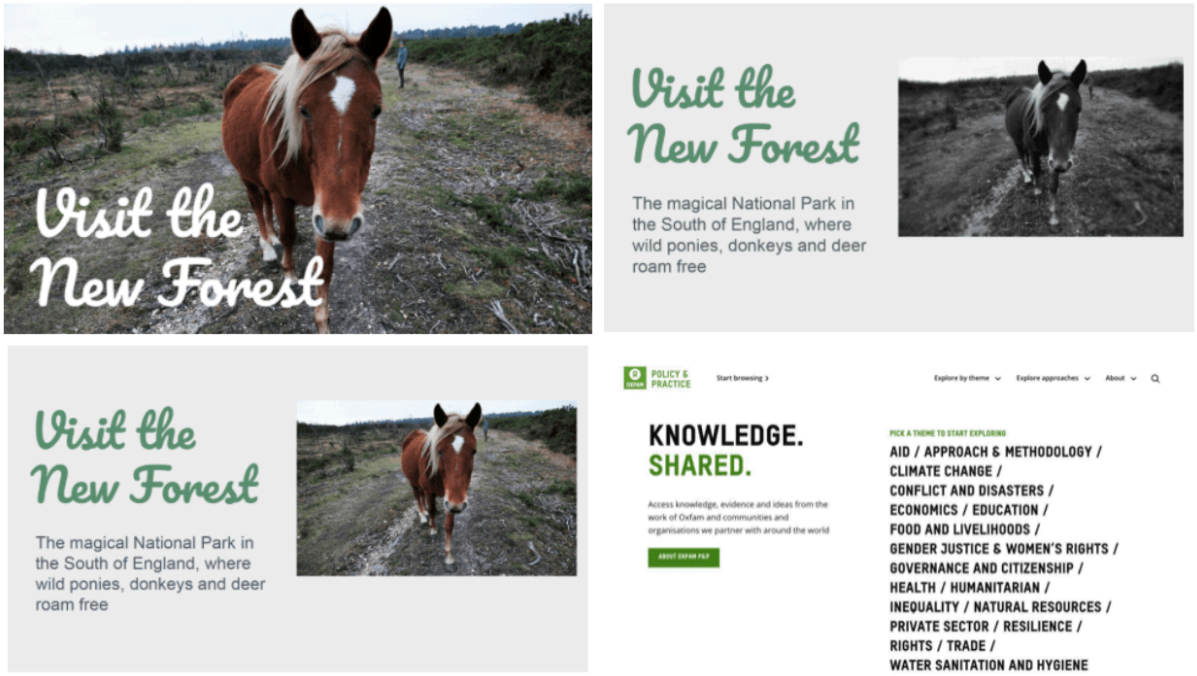

Figure 7: Websites with different amounts of elements. (Illustrations by [66])

The next question asked participants which image format was the most efficient. 49% (n=38) of participants answered WEBP. WEBP is one of the most efficient formats for photographs, however, the AVIF format is less than half the size of WEBP. The drawback of AVIF is that it ships with less compatibility. When compared to the practices section, 45.5% answered that they use JPEG as the image format in the current development process. Therefore, a legitimate claim is that participants are aware that WEBP is a more sustainable image format, but they still prefer the less sustainable option, JPEG.

In regards to fonts, 90% (n=69) of the participants answered that system fonts are the most energy-efficient and sustainable when loading web pages, which according to Greenwood is correct [14]. However, in the practices section, a majority (44.2%, n=34) of participants answered that they use external fonts ”Often” and 16.9% (n=13) ”Always” use external fonts, showing a discrepancy between their awareness and practices regarding the use of fonts.

After analyzing the answers, we constructed a chart that compares the average number of correct answers in the awareness section, against the years of working experience of each individual. The collected data were categorized into four distinct sections based on the participants' working experience: students with no prior experience, participants with less than a year of experience, those with one to five years of experience, and those with over five years of working experience.

Afterward, the participant groups were further subdivided into four distinct levels of education attained: High School, Vocational School, Bachelor's degree, and Master's Degree. We undertook this categorization to investigate whether there exists any correlation between education levels and the level of awareness of Sustainable Web Design. The x-axis of the chart represents the participant's years of experience, while the y-axis represents the average score from the awareness test, grouped into the participant's working experience. The analyzed data shows that the overall average score of all participant groups was 69%, represented by the purple line. The participant group that had less than a year of experience scored the highest average score on the awareness test, with 79%, while the students scored the lowest on average with 58%. The groups with participants who had between one to five years of experience and more than five years of experience, had average scores of 67% and 71% respectively, where the latter scored higher.

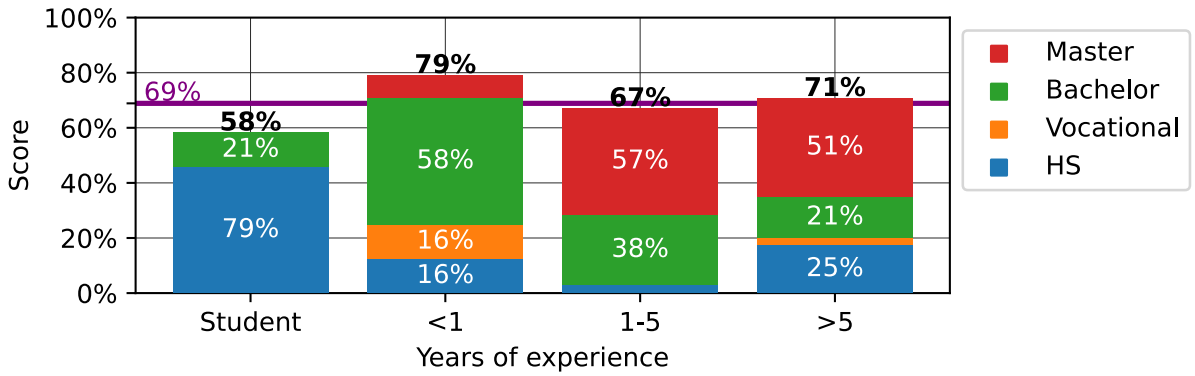

Figure 8: Chart comparing the awareness score with years of experience and educational background.

Finally, the two last questions in the questionnaire were opinion-based questions regarding the energy consumption of bot traffic and the overall environmental impact of website traffic. Here the participant was given a Likert scale from 1 (Not at all) to 5 (Very much). Most participants believed that websites and bot traffic have a medium to high impact on the environment. The average response from participants was a score of 3.49 for websites and 3.55 for bot traffic. By combining the scores of 4 and 5, which are considered a fair amount, 56% (n=46) of all participants answered this range for bot traffic and 46% (n=36) for websites.

3.3 Conclusion

The purpose of this study was to investigate the awareness and practices of web developers with regard to Sustainable Web Design. The survey participants were generally conscious of the impact of the Internet on the environment and recognized which practices were more sustainable. However, they did not always utilize the most environmentally-friendly practices when it came to factors such as file formats, font subsetting, and color usage. To promote standardized Sustainable Web Design, we suggest a more extensive and systematic approach involving all stakeholders in the ecosystem. Due to the limitations of this study, including the sample size of the questionnaire and the lack of qualitative data, a qualitative study for further research is needed. A larger sample size could have provided a more accurate representation of the industry, while qualitative data might have offered insights into the reasons behind the insufficient use of sustainable development and design methods. Future research should concentrate on identifying why the web design industry is aware of sustainable web practices but not entirely implementing them.

4 Study 2: Challenges and Barriers

This qualitative study builds upon the research and conclusions from Study 1: Awareness and Practices, where it was established that practitioners in the web development industry seem to be aware of sustainable development methods, but do not seem to prioritize implementing them in their digital products. This study aimed to gain the necessary insight to better understand the apparent lack of sustainable practices in the industry, by understanding the challenges and barriers among practitioners, prospective practitioners, and academia. This correlates to the second problem statement of this thesis, "*What are the current challenges and barriers to implementing Sustainable Web Design?*". The findings from this study have the potential to improve future solutions, resources, and initiatives that will be better suited to overcome the current challenges and meet the needs of the industry. The research findings presented in this study have been submitted for review to the Interact 2023 conference and are currently pending acceptance notification.

4.1 Methods

To gain the necessary qualitative insight into how practitioners' experiences with Sustainable Web Design and development, a series of semi-structured interviews were conducted. The reason for conducting semi-structured interviews, as opposed to structured or unstructured interviews, was that according to [67] semi-structured interviews are more powerful in qualitative research, due to their flexibility and adaptability in nature. Semi-structured interviews are also better suited for gaining more in-depth information from the participants, as the questions often are open and non-leading, meaning that the participants can express themselves more openly and without bias from the interviewer. All interviews were anonymized.

4.1.1 Demographics

The participants in the qualitative study were all from Norway and had roles connected to either design or web development. There were in total 27 participants, who were categorized into three distinct groups: practitioners (n=14), prospective practitioners (n=8), and academia (n=5). Practitioners (P.) refer to participants that currently work within the web development industry. Prospective practitioners (P.P.) are participants who currently are students at universities within

the field of design or web development, that will enter the working industry as employees within a few years. The group labeled Academia (A.) are representatives from different universities, who all had the common role as study program leaders of either design or web development programs.

In total, there were 15 male and 12 female participants in this study. In regards to age, different age groups were defined to group different participants together, to simplify analysis and further ensure the anonymity of the interviewees. A total of eight were between the ages of 18 to 24, ten were between 25 and 34, and nine participants were above 35 years old. The distribution of working experience in the industry was split evenly, with 14 participants who had less than 5 years of working experience, and 13 who had over 5 years of working experience in the industry. When asked about their defined roles either within academia, industry, or as prospective practitioners, the majority (n=19) of the participants identified as developers and the remaining (n=8) as being designers.

4.1.2 Interview Guidelines

In this study, two separate interview guidelines were developed, depending on the role of the participant that would be interviewed. One interview guideline was created for the practitioners and prospective practitioners, and another guideline for participants within academia representing different universities. The reason for having separate interview guidelines was to gain insight into how academia integrated sustainability into the study program curriculum, discover challenges in implementing sustainability into the curriculum, and learn about their future plans for including more sustainability. Additionally, participants within academia were asked about how accessibility was addressed in the curriculum. Both interview guidelines aimed to identify and understand challenges and barriers within Sustainable Web Design. No specific challenges or barriers were mentioned by the researchers, to ensure there were no leading questions, allowing the participants to freely express their opinions and statements. The interviews were conducted both online and in person with one participant and two researchers at a time. The interview period lasted from February to March 2023, where each interview lasted approximately 35 minutes on average. The shortest interview lasted 20 minutes and the longest lasted 55 minutes. This variation depended much on the participant's prior experiences in the industry or knowledge of Sustainable Web Design. The participants were shortly introduced to the main interview topics that would be discussed, along with a consent form for the data collection and usage. Dur-

ing the interviews, transcription was done by one researcher while another led the discussion, to improve the overall experience of the interview, and gather the information in an effective way.

The interview guideline for practitioners and prospective practitioners consisted of four parts containing a total of 32 questions (see Appendix B for the full interview guideline). The first part was about demographics. The demographics part consisted of questions related to their education, experience in the industry, their current roles, and generic demographics. The second part focused on the development process of the participant's current projects and how the development process is structured, including team organization, development methodologies, and decision-making processes. The third part explored the participant's familiarity with web accessibility concerns and experiences with Web Content Accessibility Guidelines (WCAG). This part was deemed relevant due to the strong links between web accessibility and web sustainability. The fourth and final part of the interview guideline focused on Sustainable Web Design, with questions about the participants' understanding of sustainability in web design and their company or study program's focus on sustainability.

The second interview guideline was dedicated to participants from academia, where multiple Norwegian universities were represented. The participants from academia were study program leaders in web development and design. This interview guideline was a single part, consisting of ten questions (see Appendix C for the full interview guideline). Unlike the interview guide for the practitioners, these questions were more focused on the study programs the participants were leading, rather than the personal motivations and experiences within sustainability and web design. Each question asked aimed specifically to gather insight into sustainability within the study program's curriculum along with plans and needs for further implementation of sustainability. The curriculum related to accessibility was also relevant in this process, to compare the experiences of accessibility and WCAG to sustainability later in the analysis.

4.1.3 Procedure and Data Analysis

After conducting the interviews, the transcriptions were controlled and validated before further analysis. All the data and transcriptions were added to a confidential spreadsheet, which was used to visualize, compare and summarize the participant's answers to each question. Each transcription was placed in a dedicated row, with a number assigned to each participant as the first

element of each row, to identify them. Each column thereafter was dedicated to each respective question, where each cell was filled in with the participant's answer. At the bottom of each column of the spreadsheet, all answers to each respective question were summarized in a single cell. This was a great method to compile all the data and maintain the collective data in an effective and clear manner, making the data manageable to analyze and reuse in the future.

To analyze the interview data, a combined approach of thematic analysis and card sorting was utilized to analyze and structure the data. This revealed the participants' challenges and barriers faced in implementing sustainability in web development and design. Thematic analysis is a qualitative data analysis approach that involves analyzing close sets of data to identify and interpret common themes. This methodology offers flexibility in analyzing data by emphasizing the identification, examination, and interpretation of qualitative information. A notable advantage of this method lies in its suitability for processing large volumes of data, which makes it particularly relevant to our study with numerous participants [68]. Thematic analysis was therefore chosen as the method for analyzing qualitative data in our study due to its flexibility and suitability for handling large amounts of information. By utilizing thematic analysis techniques on summarized spreadsheet data, we were able to uncover patterns and recurring themes within the data. Afterward, an open card sorting methodology was used to classify and prioritize the challenges based on their perceived importance within the development process. Card sorting is a qualitative research method in the field of design, where the goal is to understand the similarity between items, categorize them into separate groups, and label the groups accurately and descriptively [69]. By conducting open card sorting, there are no predefined categories or groups of information, giving the opportunity to generate and label as many categories as needed. In practice, each group member began by reading through the interview data and, while using a Miro Board, created Post-it notes for each challenge, barrier, need, or other complaints the participants provided. These Post-it notes were placed in predefined categories based on the interview guide (Development Process, Sustainability, or Accessibility). Afterward, we grouped Post-it notes from all members into their respective categories and compiled a list of common challenges and barriers found in each Post-it note.

4.2 Results

From analyzing the interviews, five distinct challenges and barriers to implementing sustainable web design were identified. These five challenges and barriers are the knowledge gap, customer-oriented prioritization, lack of motivation in the industry, comprehension challenge, and lack of sustainability within academia. Some of these challenges are closely connected to each other, as the plausible causes for each challenge might be similar. However, each challenge aims to identify each sector or area of web development as cumulative challenges originating from several smaller challenges identified earlier in the analysis. In each challenge, relevant data will support the statements made, by quotes and data collected from the participants in the qualitative study. The participants that represented each study program, will be referred to as participants from academia (A.), participants who work professionally within the field of the web as practitioners (P.), and students within web development as prospective practitioners (P.P.).

4.2.1 Knowledge Gap

Practitioners and prospective practitioners have reported that the primary challenge to implementing sustainable design in the development process is a lack of information, knowledge, or guidelines. However, these practitioners hold a positive attitude towards guidelines and believe that their companies could benefit from them, making it easier to start implementing sustainable design practices.

All practitioners and prospective practitioners presented a lack of information, knowledge, or guidelines as a significant challenge to implementing sustainable design practices. A practitioner expressed this as ”We don’t know enough to be sure of how to implement it as part of our solutions, so I crave more knowledge”. Another prospective practitioner mentioned, ”I would need more information because there are not many resources about it”. A group of participants (n=6) put emphasis on the importance of clear and structured guidelines for Sustainable Web Design, with one prospective practitioner stating ”Structured and readable guidelines like WCAG could be helpful”. To effectively convey the guidelines, another prospective practitioner suggested ”A website with information such as encyclopedias, where you can find guidelines explained in a simple way would be a step in the right direction”. Practitioners expressed a positive demeanor while mentioning ”A guideline could help to make it easier for my company to start implementing Sustainable Web Design”.

4.2.2 Customer-Oriented Prioritization

This challenge entails how practitioners are failing to convince customers to use and prioritize Sustainable Web Design in their development process. Several practitioners suggest educating customers about the benefits of sustainability to encourage them.

As stated by the practitioners, customers often do not prioritize sustainable practices in the development process due to their attitudes and priorities. Most practitioners (n=10) reported the need to follow specific requirements given by the customers, which disrupts the practitioners' advocation for Sustainable Web Design. A practitioner stated, "Whenever I try to advocate sustainable design for a project, I always face resistance from the customer". Other practitioners have noticed a potential lack of awareness and interest among customers when it comes to Sustainable Web Design and the benefits it offers. The customers focus on laws and regulations, regarding universal design, over the implementation of sustainable measures. In an exercise, the participants ranked categories in their development process by importance. The most prioritized category was accessibility, followed by code maintainability, scalability, code efficiency, Search Engine Optimization (SEO), and sustainability. Several practitioners have suggested that educating customers about the benefits of Sustainable Web Design could be a useful strategy to increase awareness and encourage them to prioritize sustainability more.

4.2.3 Lack of Motivation in the Industry

Considering how practitioners are positive toward implementing sustainability into their projects, we need to consider other factors that prevent them from doing so. The practitioners report their colleagues as difficult to convince, due to a lack of open-mindedness and knowledge regarding Sustainable Web Design. Accessibility was the highest priority among practitioners, with the motivator being regulatory requirements and fines. Overall practitioners are motivated to raise awareness about the importance of sustainability in web design.

Most participants (n=21) expressed a positive attitude when asked about implementing sustainability in their projects. However, they reported that prior attempts of convincing their colleagues of Sustainable Web Design's importance and environmental impact were very difficult. A practitioner stated that tasks related to sustainability were "Swept under the carpet and placed at the bottom of the backlog". The same practitioner identified inexperience with digital sustainability among team members as a core barrier to their open-mindedness and noted the team

members' programming choices appeared to be made without the awareness of the potential environmental effects. As mentioned in the Knowledge Gap section, on average the highest prioritized concern of our participants was that related to accessibility, with the reason being regulatory requirements as a significant motivator. For six participants, sustainability was ranked second to last, and for seven participants, sustainability was ranked least prioritized. A single participant did not want to include sustainability in their list of priorities. By comparing this data, over 63% of participants did not give priority to sustainability in their decision-making process. To gain insight into what motivators drive practitioners to follow Sustainable Web Design measures, we examined their top priority: accessibility. By examining accessibility we gain insight into what makes practitioners prioritize one concern over another. The practitioners work extensively with WCAG, therefore, we asked the practitioners (n=14) about why they follow and use WCAG's guidelines. Regulations and fines were reported as the primary motivator by most (n=10), however, nine practitioners acknowledged the benefits of designing for everyone. One practitioner in particular stated, "First and foremost, it is regulated by law and very important for us to be able to reach out to everyone. (...) We wish for anyone to be able to use what we create".

4.2.4 Comprehension Challenge

The comprehension challenge entails that there is a lack of comprehension and understanding of sustainability within web development. This challenge became apparent when asking the practitioners and prospective practitioners questions related to sustainability.

When asked to describe sustainability within web development, the majority of participants demonstrated some familiarity with sustainable development methods. The methods mentioned by participants were code efficiency, image optimization, hosting, user experience, reusability, and responsibility. Several participants stressed the significance of writing efficient code, which involves reducing the use of external libraries, reusing code, and adhering to the DRY principle. In addition to that, optimizing the code to decrease the amount of data transmitted to and from the server was emphasized, and recommended implementing code-splitting and lazy loading. A few participants advised reducing image sizes by compressing or using monochrome images and compressing videos, as well as being mindful of the number of images utilized, as they affect page weight. Green hosting and servers situated in clean energy areas were recommended by two participants, along with minimizing server storage and optimizing data delivery to reduce energy

consumption on both servers and user devices. Several participants suggested that Sustainable Web Design should prioritize the user experience by minimizing user flow and time spent on a website. The participants also highlighted the importance of accessibility and universal design. Two participants suggested creating reusable components or code for a website, while a single participant considered the social and psychological impacts of websites, stressing the importance of designing to influence people's behavior.

However, only four participants were able to accurately define sustainability by demonstrating knowledge of how the Internet affects the environment, carbon footprint, and CO2 emissions produced by the growing demand and industry linked to the Industry. Thus demonstrating an adequate level of comprehension, of not only methods that contribute to less environmental impact, but also the reasons why these methods are sustainable and important to improve the environmental impact of the industry.

Practitioners and prospective practitioners (n=22) were then asked to identify necessary measures for implementing sustainability in the development process. The question did not have any predefined suggestions for the participants, as in leading the participants toward a specific form of resource. The question was *"What is necessary to improve the implementation of sustainability in the development process?*". Many participants believed there was a need for more information or resources for Sustainable Web Design. The following results summarized the answers from the participants:

Guidelines: Over half (n=14) suggested that informative resources like a guideline would greatly benefit sustainable development, whereas some participants cited WCAG as a similar alternative. A participant (P.) answered that "Good guidelines with rules for how to implement sustainability can be efficient", while another participant (P.) stated that "An overall, well-made checklist would be nice". Simultaneously, the same participants suggested an informative website with all collected information regarding Sustainable Web Design. A participant (P.P.) stated, "(...) Like Wikipedia, where you can find guidelines explained in a simple way with real-life examples."

Simple, Clear, Interactive: Many participants also reported that they had a need for clear definitions of what Sustainable Web Design actually entails. To achieve this, the participants wanted simple and clearly defined methods and information regarding sustainability. Lastly, participants asked for interactivity, like code snippets, documentation, or tutorials like W3Schools. A

participant (P.P.) stated that ”It could be fun to learn and use sustainability if it was in a gamification format, more interactive, using images, videos, etc. I like W3Schools for their ’try it yourself’ exercises.”

Tools: Some participants reported that they wanted tools, similar to the existing accessibility tools used in web design, like WAVE[5]. This could automate the implementation of sustainability or check how sustainable their product is.

To better understand how existing guidelines are utilized and the possible difficulties in using these, we asked the participants about their prior experiences and their relation to working with the current web accessibility guidelines. The aim of this section was to find issues and challenges to reading and using WCAG, by examining their prior experience and feedback. When asked about their experience reading WCAG, most participants reported that it is difficult to read and understand the WCAG guidelines, which is the reason that over half of the participants (n=15) use alternative solutions like WAVE, internal checklists, or UU-tilsynet[6]. These issues are common among all participants, along with the WCAG guidelines being tedious to use, leading to frustration and demotivation among practitioners. Other complaints of the WCAG guidelines were low legibility and difficulty in navigating the website.

4.2.5 Lack of Sustainability within Academia

The last significant challenge entails that there is a lack of sustainability within academia, more specifically in the university curriculum for prospective practitioners. In this study, we made efforts to see how different universities focus on sustainability within each respective study program that relates to design or web development. These study programs included web development, interaction design, and graphic design. To fully understand the greater picture and evaluate the current implementation of sustainability in academia, we gathered insight from study program leaders and prospective practitioners.

When asked how sustainability is integrated into the study programs, there were varying degrees of how much focus is dedicated directly to this topic. A common response from all participants (A.) was the focus on the UN’s sustainability goals in student projects or that it is an obligatory part of the bachelor thesis. When asked to elaborate, a participant (A.) explained that it was ”obligatory in the assignment to get the project plan for the thesis approved, but not necessary

[5]The Online Web Accessibility Evaluation Tool (WAVE) checks page accessibility
[6]The Authority for Universal Design of ICT in Norway

in the final report. This was a way to make students evaluate how their product in the bachelor thesis could impact the environment". Other participants (A.) explained that was a reoccurring part of several assignments in the different courses and the final bachelor thesis, where it was depending on each assignment whether it was obligatory or not.

For most study programs, participants (A.) reported that sustainability most often is indirectly or partially introduced to students and prospective participants. However, in the context of Sustainable Web Design, participants (P.P.) report that it is indirectly introduced as "code efficiency" or "web design methodology", not as a curriculum specifically promoting sustainability. This is confirmed by the prospective practitioners, where most (n=6), could define some specific sustainable methods but were unable to define or lacked an adequate understanding of the overall sustainability concept in web design. According to a participant (P.P.) who is a graduating student, there is "A tiny bit, but not a lot. We had some about accessibility which we might relate to sustainability. We also had about the UN sustainability goals. [...] did not have any subject dedicated to or focused on it". This and similar statements were reoccurring among most participants (P.P.).

There are improvements made to include more sustainability, as reported by participants (A.), stating there is a gradual inclusion of sustainability through new subjects or revisions to course descriptions, with explicit incorporation of sustainability. Additionally, there was a strong emphasis on reflecting on how sustainability impacts projects and their focus on the various pillars of sustainability. For example, the first-year students knew more about sustainability due to their updated curriculum with more focus on sustainable development. The participants (P.P.) who were first-year students were more capable to categorize and demonstrate knowledge in Sustainable Web Design than the others, where one participant (P.P.) reported: "We learned how to create our websites a bit more sustainable, some methods, learned some tools to analyze with, referring to carbon footprint measurements". This proves the statements from participants of academia and our previous research in regard to NTNU, that there are attempts to increase sustainability in the curriculum being made.

4.3 Conclusion

In this qualitative study, several challenges and barriers associated with implementing Sustainable Web Design have been identified. Based on the data and insight gathered and analyzed, we

were able to categorize the following challenges: Knowledge gap, customer-oriented prioritization, lack of motivation in the Industry, comprehension challenge, and lack of sustainability in academia, where the knowledge gap emerged as the most significant challenge.

The participants expressed the need for more informative resources to educate themselves in Sustainable Web Design, where informative digital solutions and guidelines were highly suggested. To address and overcome these challenges, especially the identified knowledge gap, similarities were drawn with web accessibility. This resulted in finding plausible initiatives that would benefit the future implementation of Sustainable Web Design, like using a top-down and bottom-up approach, as suggested for web accessibility [55]. This also underscored that guidelines as a plausible solution. However, insight gathered from prior experiences of participants with WCAG showed that there are legibility issues, comprehension challenges, and navigational issues when using the official guidelines, leading to the usage of alternative tools and simplified versions. This gave us valuable insight to later use in implementing our own solutions, showing that precise, clear, and simple wording, a clearly defined structure, and navigation, as in information architecture, are vital to ensure legibility and comprehension among practitioners. Overcoming these challenges is vital to equipping stakeholders with the necessary knowledge, information, and skills to prioritize Sustainable Web Design.

5 Study 3: Guidelines

This chapter presents comprehensive guidelines for Sustainable Web Design, developed through a thorough investigation of best practices and insights gained from previous studies (See chapter 2, and 3). These studies revealed a clear need for guidelines that can be used by both industry and academia to promote Sustainable Web Design practices. The goal of the creation of these guidelines is to provide a valuable resource for all stakeholders seeking to integrate sustainable practices into their work. By creating and testing these guidelines, we aimed to address our third research question: "*What are the main practices that should be part of guidelines for Sustainable Web Design?*"

5.1 Methods

This section describes the process of how the guidelines were developed, as a response to the findings from Study 1 and Study 2.

5.1.1 Researching Existing Guidelines

To develop a practical and effective guideline for Sustainable Web Design, it was essential to first gain a clear understanding of the purpose and scope of such a document by exploring existing guidelines for the Web. A widely used and standardized guideline is the Web Content Accessibility Guidelines (WCAG), which offers a wide variety of recommendations for creating more accessible web pages. It was developed by the World Wide Web Consortium and was introduced as an ISO standard in 2012 [70]. We did a thorough analysis of the WCAG at their Quick Reference website [71], to see how the guideline is structured and explore the main criticism presented in Study 2 (see Section 4.2.4). The guideline is divided into sections that correspond to the four main principles of WCAG 2.1: perceivable, operable, understandable, and robust. Each principle is then further divided into guidelines, and each guideline includes success criteria that outline specific requirements for meeting that guideline. Their Quick Reference website also includes links to more detailed explanations of each guideline, as well as resources for implementation. In terms of examples, the quick reference provides concise and clear examples for each success criterion, which can help users understand what the practice is asking for and how to implement it.

The WCAG served as a valuable source of inspiration for our work. However, Study 2 and the literature review conducted in the Background chapter revealed that several stakeholders found the format of WCAG too complex and challenging to relate to. Interestingly, only a small number of participants actually read and utilized the original WCAG as presented on the W3C website, according to the participants of Study 2. Instead, they relied on simplified versions or automated evaluation tools. This feedback underscored the importance of having guidelines that are clear and user-friendly, with specific instructions. In light of these findings, we decided to adopt a different approach from the WCAG Quick Reference and drew inspiration from the Norwegian Authority for Universal Design (see Figure 9 for a comparison of the two). Their website [72] presents practical solutions for implementing WCAG, organized by content and grouped into easily understandable categories such as links, lists, sound, and video. This approach differentiates it from the WCAG quick reference, which primarily organizes content based on principles.

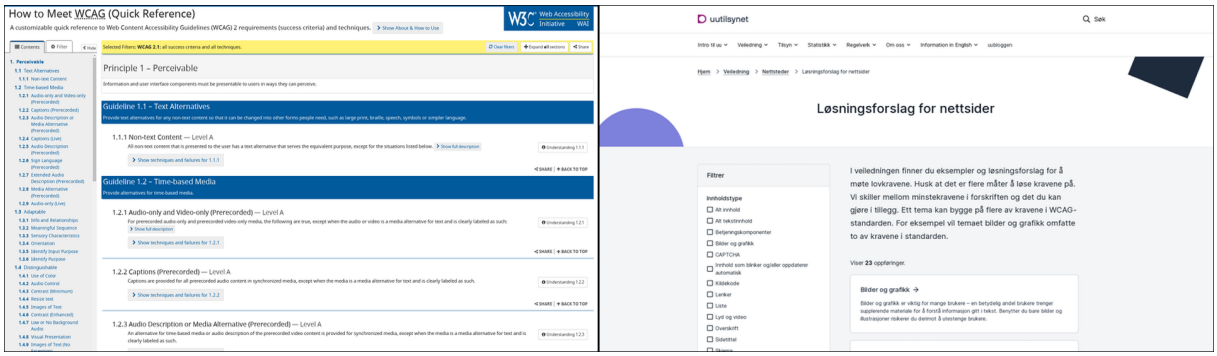

Figure 9: Comparison of websites. WCAG Quick Reference to the left, and the Norwegian Authority for Universal Design to the right.

As of this writing, there are no published guidelines for Sustainable Web Design. However, a W3C group of digital professionals named ”Sustainable Web Design Community Group” [65] are currently working on a draft, as revealed in the Advocates of Sustainable Web section. The group’s mission is to provide digital professionals with the necessary tools, resources, and guidelines to incorporate environmental sustainability principles into their workflows and work practices. Based on their publicly available wiki [73], their guidelines will be divided into front-end and back-end sections, covering topics such as HTML, CSS, JavaScript, syntax, databases, assets, and more. Additionally, they have separate work going on for guidelines related to UX design and hosting, among others. The front-end and back-end guidelines are structured similarly to WCAG, with titles and success criteria, but they also include information on the impact

and effort of following each guideline, along with benefits and examples reasoned by references.

To summarize the key considerations for developing Sustainable Web Design guidelines, the following presents a compilation of lessons learned from the findings of Studies 1 and 2, as well as insights gained from the websites that present WCAG:

- The guidelines need to be readable and easy to use.
- The guidelines need to address the needs of several stakeholders including developers, designers, DevOps, Management, and Content Creators.
- The guidelines must include clear instructions on how to be implemented.
- The guidelines should be divided into easy-to-understand categories.
- Stakeholders prefer using interactive tools for incorporating practices in their development processes.

5.1.2 Gathering Sustainable Practices

In order to identify sustainable design practices, we conducted a literature review including ”Sustainable Web Design” [14], ”Designing for Sustainability” [12], and the strategies presented at the website sustainablewebdesign.org. The identified practices were then compiled into a spreadsheet (see Appendix E: Sustainable Practices), which included seven separate sheets: ”Images”, ”SEO”, ”Design”, ”Workflows”, ”Videos”, ”Fonts”, and ”Colors”. Each sheet includes a table divided into two columns, one to list all the sustainable practices, and another to provide the source from which the practice was derived. The ”Images” sheet includes 11 practices, the ”SEO” sheet includes 7 practices, the ”Design” sheet includes 12 practices, the ”Workflows” sheet includes 13 practices, the ”Videos” sheet includes 6 practices, the ”Fonts” sheet includes 7 practices, and the ”Colors” sheet includes 1 practice. This systematic approach to gathering and organizing sustainable design practices allowed us to thoroughly assess the available literature and identify best practices in a comprehensive and structured manner. This, along with the findings from previous Studies 1 and 2, was further used to develop content for the Sustainable Web Design guideline.

5.1.3 Designing the Guidelines

Based on an analysis of the collected sustainable practices, six key categories were identified that we aimed to cover: Images, Videos, Typography, Design, Code, and Hosting. These categories were selected to provide a comprehensive range of sustainable design practices and were informed by Studies 1 and 2, which highlighted a clear need for guidelines relating to images, videos, and typography, as these practices have been less commonly implemented in a sustainable manner. In addition to these categories, we also recognized the need for guidelines relating to code and hosting, as these were identified as other areas where participants in our previous studies lacked knowledge. The studies also indicated that guidelines needed to be easy to read and navigate, to avoid the complexity often found by using WCAG. Furthermore, it was essential to ensure that the guidelines were relevant to all stakeholders and not just to one or two separate groups. Having identified the categories and considered the important lessons from the previous studies, the most relevant sustainable practices were selected and evaluated from each category in our spreadsheet. This resulted in four guidelines for images, three for video, four for fonts, six for design, eight for code, and four for hosting. We then turned each chosen practice into separate, easy-to-understand guidelines. The structure we used for this is explained next:

1. **Title:** Each guideline's title consists of a unique numeric identifier (Such as 1.1) and a brief, descriptive text. It is meant to aid users in identifying and comprehending the purpose of the guidelines quickly. It helps organize the guidelines in a structured manner and makes them easier to navigate. Additionally, they contribute to an easier understanding of what to expect from the guidelines.

2. **Short Description (Optionally: Quick Reference)**: The short description accompanying each guideline serves as a brief summary, providing users with a quick overview of the guideline's content and purpose. This enables users to quickly determine if a particular guideline is relevant to their needs, without having to read the entire guideline in detail. For longer guidelines, a quick reference is also included alongside the short description. The quick reference provides a summary of the key points and actions needed to implement the guideline in a concise and easily understandable manner. This enables users to quickly and easily implement the guideline without having to read through the main description.

3. **Description:** This section's goal is to provide users with a more in-depth understanding of the guideline. This can help users make informed decisions about how to implement the guideline.

4. **How to implement:** Provides users with practical guidance on how to apply the guideline's recommended practice. This section includes step-by-step instructions that are designed to help users meet the guideline's requirements effectively. By providing clear and concise instructions, users can more easily understand how to implement the guideline and can ensure that they are following best practices. The section's step-by-step approach can also help users break down complex processes into manageable tasks, promoting more effective and efficient implementation.

5. **Why:** By explaining the benefits of following each Sustainable Web Design guideline, users can gain a deeper understanding of the recommended practice and its positive impact. This context can help users appreciate the importance of adopting best practices and be more motivated to implement them.

6. **References:** This section is included to support users in understanding the sources and evidence behind the guideline's recommended practice. This can help users to access additional relevant information and resources to better understand the guideline's content.

5.1.4 Testing the Guideline for Clarity and Relevance

A survey was created to collect feedback on the guidelines intended for future work. The main objective was to evaluate the clarity and relevance of the guideline categories, titles, and content. While user testing was initially planned as part of the project's scope, conducting a thorough workshop for user testing was only considered if time allowed. However, due to the numerous contributions of this thesis, we were unable to prioritize organizing a workshop. Instead, we gathered feedback through an online survey platform, due to its flexibility, convenience, and ability to offer diverse question options [74].

The survey (see Appendix F) consisted of two main sections: demographics and guidelines. The demographic questions included the participant's age group, gender, and current role. The guideline-related questions were aimed at evaluating the clarity of the guideline sections (such as Images, Videos, etc.), assessing the relevance of guideline titles, identifying any guidelines that the participant felt were missing or should not be included, and checking the overall under-

standability of the guidelines. The survey used a Likert scale from ”To no degree” up to ”To a large degree”.

A website was created (see chapter Dissemination of Guidelines) to disseminate the guidelines and, at the same time, make it possible to gather feedback. The website used for gathering feedback was a simplified version of the final version, which only included a homepage, guideline page, and checklist page (See figure 10). To ensure that we received valuable feedback, we recommended that the participants spend a minimum of 10 minutes reading through the guidelines. We explicitly instructed the participants to focus solely on the guidelines while providing their feedback, as the survey questions were solely related to the guidelines and not about the usability or accessibility concerns of the website itself. The guidelines on the testing website were divided into already established categories mentioned in ”Designing the guidelines”, each of which contained several guidelines for the participants to explore. The website URL, sustainableweb.net, and the online survey created with Nettskjema were shared via email with a selected group of participants from Study 2, as well as with individuals who had no prior knowledge of our work. In total, we had 11 participants who took part in the feedback process.

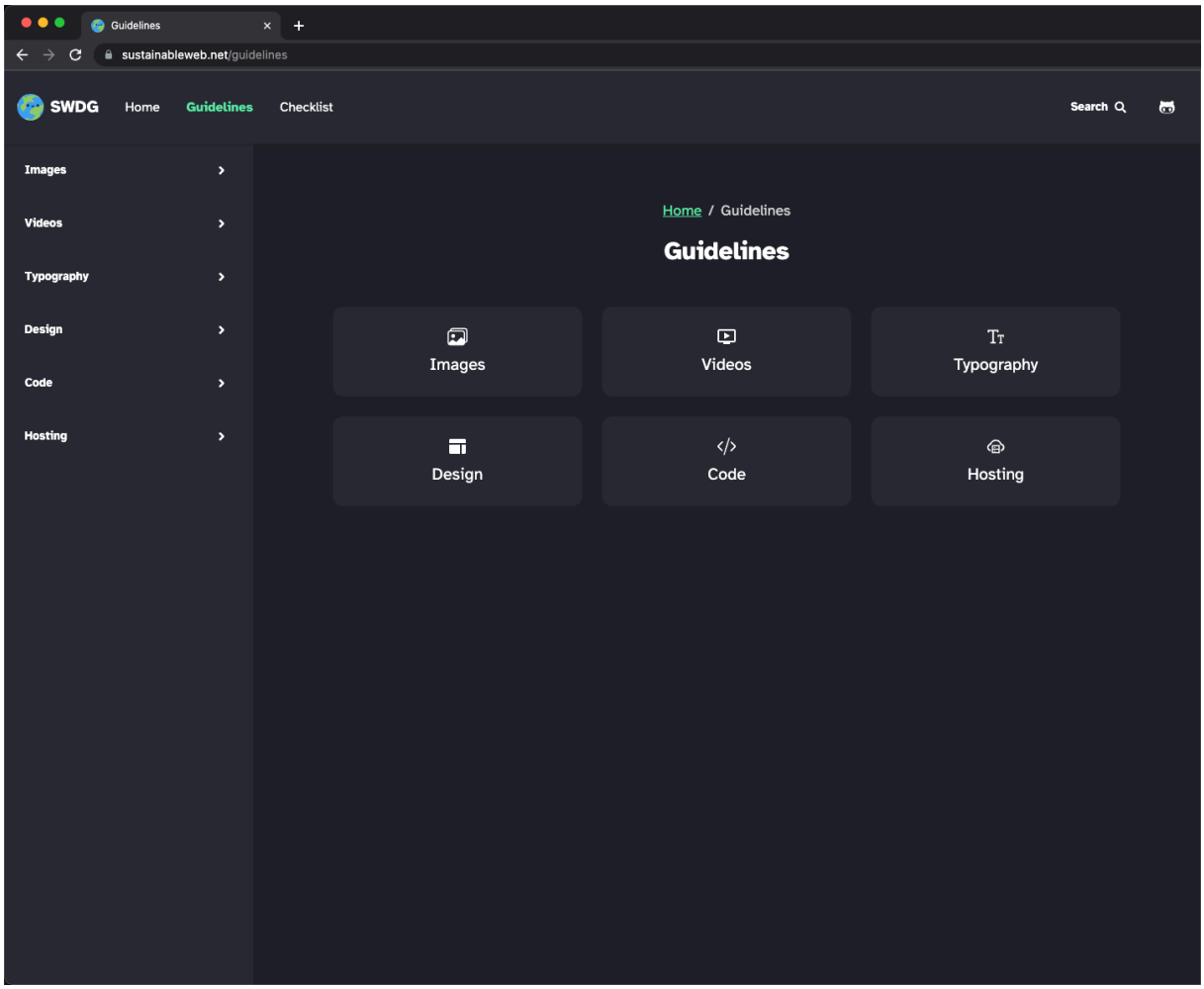

Figure 10: A screenshot of sustainableweb.net as presented to the participants, when conducting user testing.

5.2 Results

This section presents the final version of our Sustainable Web Design Guidelines and the feedback from our user testing. We developed guidelines for Sustainable Web Design to address the fact that stakeholders within web design do not have enough information on how to implement sustainable web solutions.

The guidelines are organized into six main categories, each containing multiple guidelines: Images, Videos, Typography, Design, Code, and Hosting. The categories are titled according to the content they cover, and their order is arbitrary; they are not ranked by importance or amount of carbon footprint impact. In total, we have 29 guidelines to help the industry create more sustainable web solutions. Each guideline follows this structure, where some include the ”Quick Reference”:

1. Title
2. Short Description (Optionally: Quick Reference)
3. Description
4. How to implement
5. Why
6. References

The guidelines presented in this chapter are simplified versions, only covering the titles and short descriptions due to the length of covering each guideline in-depth. The full guidelines can be examined at our website sustainableweb.net/guidelines, or see Appendix D.

5.2.1 Guidelines for Images

As one of the biggest contributors to carbon emissions on an average website [14], these guidelines provide recommendations to select the most appropriate image format based on the content and purpose of each image, along with an appropriate compression level. The guidelines also provide recommendations for optimizing vectorized images to ensure faster loading times, decreased file size, and improved SEO. In addition, they suggest a creative approach of replacing images completely by using CSS and SVG to create visually engaging designs. Finally, the guidelines recommend the use of responsive sizing to provide images in different sizes and resolutions based on the user's screen size, to minimize data usage and improve page load times.

1.1 Compressing Images	Use the most efficient image format and compression level.
1.2 Optimizing SVG	All SVG images must be optimized by reducing unnecessary code.
1.3 Creative Use of CSS and SVG	Whenever possible, images and photographs should be replaced with creative CSS or lightweight SVG.
1.4 Responsive Sizing	All rasterized images must be sized responsively using the "srcset" and "sizes" attributes.

Table 1: Sustainable guidelines for images.

5.2.2 Guidelines for Videos

While videos may not be used as frequently as images, they have a greater impact on carbon emissions, making them an even more significant contributor to the carbon footprint of a website when being used [14]. The guidelines provide recommendations for selecting the most appropriate container format and efficient codec for video compression, and in turn, significantly reduce the file size without compromising video quality. They also suggest avoiding auto-playing videos and audio to save resources and improve user experience. The guidelines also recommend the use of web animations instead of videos for conveying information, as they typically require less bandwidth and storage, and offer accessibility features such as text alternatives and keyboard controls.

2.1 Compressing Videos	Media should be contained inside a format that supports subtitles, and encoded with efficient video- and audio codecs.
2.2 Auto-Playing	Avoid using auto-play functionality of media, including background videos.
2.3 Animations	Consider using web animations over video whenever possible.

Table 2: Sustainable guidelines for videos.

5.2.3 Guidelines for Typography

This section of the guidelines provides recommendations for optimizing font usage. For instance, a guideline refers to the use of built-in system fonts to improve loading times and increase text legibility. However, if custom fonts are necessary, the guidelines suggest using the WOFF2 font format, which results in smaller file sizes and faster loading times. The guidelines also recommend using SVG icons instead of icon fonts to reduce server requests and improve loading times. Finally, font subsetting is suggested to reduce bandwidth usage by removing unnecessary glyphs and characters when using external fonts.

3.1 System Fonts	Prioritize using built-in system fonts over external fonts.
3.2 Font Format	Prioritize using the WOFF2 font format for external fonts.
3.3 Using SVG Icons	Prioritize using SVG icons over icon fonts.
3.4 Font Subsetting	Do font-subsetting for external fonts to create a custom font that only includes the characters needed.

Table 3: Sustainable guidelines for typography.

5.2.4 Guidelines for Design

This section of the guidelines offers recommendations for various design elements and decisions. They provide advice on implementing features such as a dark mode to reduce eye strain and energy consumption, designing websites with a user-centric approach, including a search bar to improve user experience, creating content with a clear objective, and adopting a mobile-first approach to enhance speed and usability. In addition, the guidelines suggest setting a page weight limit to improve loading times and reduce carbon emissions.

4.1 Dark Mode Feature	Offer a dark mode feature to reduce energy consumption on OLED screens.
4.2 User Journey	Design the user journey of the website to be as intuitive and efficient as possible.
4.3 Search Bar	For websites consisting of more than five pages, provide a search bar that can be used to find content efficiently.
4.4 Content With Purpose	Focus on minimalism, by only including content that has a clear purpose for your design.
4.5 Mobile-First Principle	Design your website using the mobile-first principle.
4.6 Page Weight Budget	Set a maximum page weight limit for your web pages.

Table 4: Sustainable guidelines for design.

5.2.5 Guidelines for Code

This section of the guidelines provides recommendations for coding practices and implementations. It outlines several best practices, including lazy loading non-critical images and media, utilizing Agile methods to enhance collaboration and project outcomes, opting for static website solutions over dynamic solutions, and carefully assessing the need for frameworks such as React or Vue.js. Additionally, the guidelines suggest caching static content like images, HTML, CSS, and JavaScript files to reduce server requests and page loading time, compressing code files to enhance page loading speed, and limiting user tracking to instances where it is justified and with explicit user consent. Finally, by adhering to the DRY (Don't Repeat Yourself) principle, developers can eliminate redundancies in process and logic.

5.1 Lazy Loading	Use lazy loading to defer the loading of non-critical media until they are needed.
5.2 Agile Methods	Use Agile methods to promote Sustainable Web Design through efficient project management and continuous improvement.
5.3 Static Solutions	Go static for your website whenever possible, including minimizing the use of JavaScript.
5.4 Frameworks	Consider whether the use of a framework is needed or not, and use them wisely.
5.5 Page Caching	Make use of caching to minimize server requests.
5.6 Compression	Minimize the size of code files by compressing them.
5.7 Avoid User Tracking	Use tracking scripts only for justified reasons and with explicit user consent.
5.8 Don't Repeat Yourself	Use the DRY (Don't repeat yourself) principle to reduce code duplication and improve code maintainability.

Table 5: Sustainable guidelines for code.

5.2.6 Guidelines for Hosting

Within this section of the guidelines, a particular emphasis is placed on the hosting and server aspects. Recommendations include prioritizing web hosting services that rely on renewable energy sources, selecting server locations in close proximity to the majority of website users, implementing GZIP[7] compression to reduce website file sizes, blocking bad bots from accessing the website, and utilizing content delivery networks (CDNs[8]) to cache website content on servers located in multiple geographic locations.

6.1 Green Hosting	Choose web hosting services that use renewable energy References (green hosting) and which are located close to the majority of your users.
6.2 GZIP Compression	Use GZIP compression for HTTP requests fetching HTML, CSS, and JavaScript files.
6.3 Block Bad Bots	Block bad bots to improve website security and reduce server load.
6.4 Using CDN	Use CDN (Content Delivery Network) if your website is used across widespread areas.

Table 6: Sustainable guidelines for hosting.

[7] A file format and a software application used for file compression and decompression
[8] A geographically distributed network of proxy servers and their data centers.

5.2.7 Feedback from User Testing

The demographics of the user test participants revealed that there were a majority of younger participants, with 63.6% (n=7) falling between the ages of 18 and 24. Only 27.3% (n=3) fell between 25-34, and a single participant was in the 45-54 age range.

The genders of the participant were 63.6% (n=7) male and 36.4% (n=4) female. When asked about their current role, a majority (63.6%, n=7) of participants were students of web development, two were developers (18.2%), one participant's role was academia, and the last participant was a student of interaction design.

When asked about the understandability of the guideline categories, the participants were mostly positive. 45.5% (n=5) answered "To a large degree", and 45.5% (n=5) "To a big degree", meaning a total of 91% (n=10) positive feedback. There was only a single participant who was neutral. When asked for additional feedback, a participant reported that "(...) the sections were quite understandable and well structured, but if one had no experience or knowledge in web development and interaction design, I think the actual information could be a little 'difficult' to understand. A little complicated, but other than that very helpful". Another participant also reported the lack of a section dedicated to sound.

To what degree did the sections (Images, videos etc.) make sense to you?

Number of submissions: 11

Submissions	Count	% of submissions	
To a large degree	5	45.5%	45.5%
To a big degree	5	45.5%	45.5%
Neutral	1	9.1%	9.1%
To some degree	0	0%	0%
To no degree	0	0%	0%

Figure 11: Table showing participant feedback on guideline sections.

When asked about how self-explanatory each guideline title was regarding its content, all participants responded positively. The majority (54.5%, n=6) answered they were self-explanatory

”To a big degree” and the rest (45.5%, n=5) answered to a large degree. When asked for additional feedback, a participant responded ”The only ones I didn’t quite understand were ’user journey’, ’content with purpose’, and ’agile methods’. I’m not quite sure what I will find here without clicking”.

To what degree are the guideline titles self-explanatory regarding its content?

Number of submissions: **11**

Submissions	Count	% of submissions	
To a large degree	5	45.5%	45.5%
To a big degree	6	54.5%	54.5%
Neutral	0	0%	0%
To some degree	0	0%	0%
To no degree	0	0%	0%

Figure 12: Table showing participant feedback on guideline titles.

When asked how understandable and readable the guidelines were overall, all participants answered positively, with a majority (63.6%, n=7) answering ”To a big degree” and the remaining 36.4% (n=4) answering ”To a large degree”. A participant requested more focus or additional information in the Font Format guideline and gave us an alternative and expanded version of the current guideline. Other feedback for the overall guidelines was a request for references to be more detailed and descriptive.

How understandable and readable was the guidelines overall?

Number of submissions: **11**

Submissions	Count	% of submissions	
To a large degree	4	36.4%	36.4%
To a big degree	7	63.6%	63.6%
Neutral	0	0%	0%
To some degree	0	0%	0%
To no degree	0	0%	0%

Figure 13: Table showing participant feedback on guideline understandability and readability.

When asked to compare our guidelines to existing web accessibility guidelines, participants were very satisfied with their overall experience. The majority (72.7%, n=8) answered ”Very satisfied” and the remaining 27.3% (n=3) were ”Somewhat satisfied” with their experience.

Compared to existing web accessibility guidelines (WCAG), how is your overall experience of our guideline?

Number of submissions: **11**

Submissions	Count	% of submissions	
Very satisfied	8	72.7%	72.7%
Somewhat satisfied	3	27.3%	27.3%
Neutral	0	0%	0%
Somewhat dissatisfied	0	0%	0%
Very dissatisfied	0	0%	0%

Figure 14: Table showing participant feedback on guideline experience compared to existing guidelines (WCAG).

To examine the feedback on the overall structure of the guidelines, we made a matrix that separated each guideline section. Here the participants could answer on a scale from ”Not at all useful” to ”Extremely useful” for each section, gaining valuable feedback on how we have structured the guideline content.

Quick Reference section: Five participants answered ”Extremely useful”, two participants ”Very useful”, and the remaining four answered that this section was ”Moderately useful”.

Description section: A majority (n=6) of participants answered that this section was ”Very useful”, four participants answered ”Extremely useful” while the remaining participants answered ”Moderately useful”.

How to implement section: A majority (n=7) answered that this was ”Extremely useful”, being the section that most participants answered most positively to. The remaining four participants answered ”Very useful”.

Why section: The majority (n=7) answered this section as being ”very useful”, three participants answered ”Extremely useful”, and the remaining participant answered ”Moderately useful”.

References section: This was reported by the participants as the least useful section of the guidelines. The most frequent answer from participants (n=5) was ”Moderately useful”, three participants answered ”Very useful”, two participants answered ”Extremely useful” and a single participant answered ”Slightly useful”.

How useful did you find the guideline sections?

Submissions	Not at all useful	Slightly useful	Moderately useful	Very useful	Extremely useful	Chart
Quick Reference	0	0	4	2	5	
Description	0	0	1	6	4	
How to implement	0	0	0	4	7	
Why?	0	0	1	7	3	
References	0	1	5	3	2	

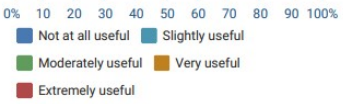

Figure 15: Matrix showing participant feedback on guideline structure.

When asked about the likelihood of using the guidelines in future projects, all participants were positive. The majority (72.7%) answered the likelihood ”To a big degree”, while the remaining

participants (27.3%) answered, ”To a large degree”.

How likely is it that you would you use the guidelines in a future project?

Number of submissions: **11**

Submissions	Count	% of submissions	
To a large degree	3	27.3%	27.3%
To a big degree	8	72.7%	72.7%
Neutral	0	0%	0%
To some degree	0	0%	0%
To no degree	0	0%	0%

Figure 16: Table of the likelihood of using guidelines in future projects.

Participants were also asked to what degree the guidelines could help them to implement Sustainable Web Design practices. Also here there was massively positive feedback, where the majority (63.6%) of all participants answered the guidelines would help ”To a big degree” while the remaining participants (36.4%) answered, ”To a large degree”.

To what degree do you think the guideline could help you to implement sustainable web design practices?

Number of submissions: **11**

Submissions	Count	% of submissions	
To a large degree	4	36.4%	36.4%
To a big degree	7	63.6%	63.6%
Neutral	0	0%	0%
To some degree	0	0%	0%
To no degree	0	0%	0%

Figure 17: Table of feedback on how the guidelines would help to implement Sustainable Web Design practices.

When asked if there were any other feedback on the Sustainable Web Design Guidelines, as in sections, guidelines, or content, a participant wanted ”Tips for frameworks for the various purposes. For example, write for which purposes you can use React, Vue.js, Sveltekit, etc”.

Lastly, there was a dedicated question for participants that represented academia, where the participant was asked ”Could the guidelines be a valuable addition to the sustainability syllabus of any of your study program courses?”. The participant from academia answered positively.

5.3 Conclusion

A comprehensive set of 29 guidelines for Sustainable Web Design was developed as a result of the collective research and studies conducted in this thesis. These guidelines aim to resolve the need for informative resources among stakeholders, which was identified as an important measure to increase the low implementation rates identified in Study 1: Awareness and Practices. Additionally, the guidelines were implemented to overcome the challenges and barriers to incorporating sustainability in the development processes identified in Study 2: Challenges and Barriers. Efforts were made to ensure the legibility and comprehensiveness of the guidelines, by gaining insight into practitioners' experiences with existing resources and guidelines. Therefore, the guidelines are divided into six main categories: Images, Videos, Typography, Design, Code, and Hosting. Each guideline is also separated into distinct sections: Title, Short Description (Optionally Quick Reference), Description, How to implement, Why, and References. Quantitative user testing was conducted online with several stakeholders, which resulted in overwhelmingly positive feedback. These guidelines provide a valuable resource for stakeholders to incorporate sustainable practices into their development processes and will contribute to a more environmentally responsible approach to digital product development.

6 Dissemination of Guidelines

The primary goal of creating Sustainable Web Design Guidelines was to provide a comprehensive resource that can be easily understood and accessed by all stakeholders. In order to make the guidelines easily accessible for everyone, we acquired the domain sustainableweb.net and developed a website to host the guidelines online. The website is currently password protected[9] until the guidelines are published. This chapter addresses the design and development process of the website, and how we addressed our own guidelines upon its development.

6.1 Methods

This section details the process of creating a website for disseminating the guidelines, including the design of wireframes, coding, and the steps taken to ensure that the website emits the least amount of carbon, by following practices from our Sustainable Web Design Guidelines.

6.1.1 Creating Wireframes

Wireframes were created in Microsoft Whiteboard[10] and Figma[11] to outline the general structure and information architecture of the website containing the Sustainable Web Design Guidelines. The purpose of creating these wireframes was to provide a rough visual representation of the website's layout and user interface, which was used as a starting point for further design iteration and development. Inspiration for the wireframes was drawn from existing documentation-based websites like Docusaurus[12] (see Figure 18) and MDN developer[13] (see Figure 19). The wireframes were designed to follow common documentation layouts, such as a header containing navigation links and a side menu for selecting guidelines. The wireframes were reviewed and validated to ensure that they met the website's objectives and provided a user-friendly experience.

[9] Use this password for accessing the website: jv0efmz38tsunepk9pslqlj6rybzsdjl
[10] A visual collaboration canvas
[11] A collaborative interface design tool: https://www.figma.com/
[12] A static-site generator: https://docusaurus.io/
[13] An open-source web platform documentation site: https://developer.mozilla.org/en-US/

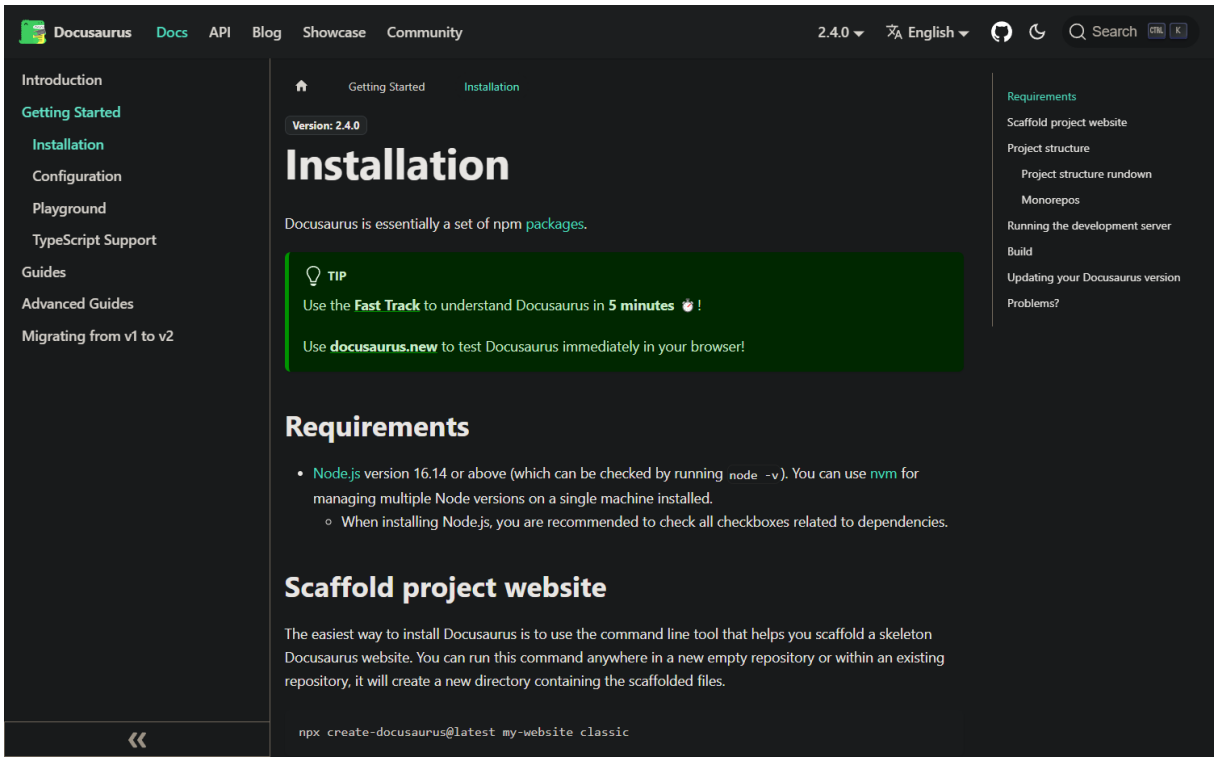

Figure 18: A screenshot from the Docusaurus documentation site.

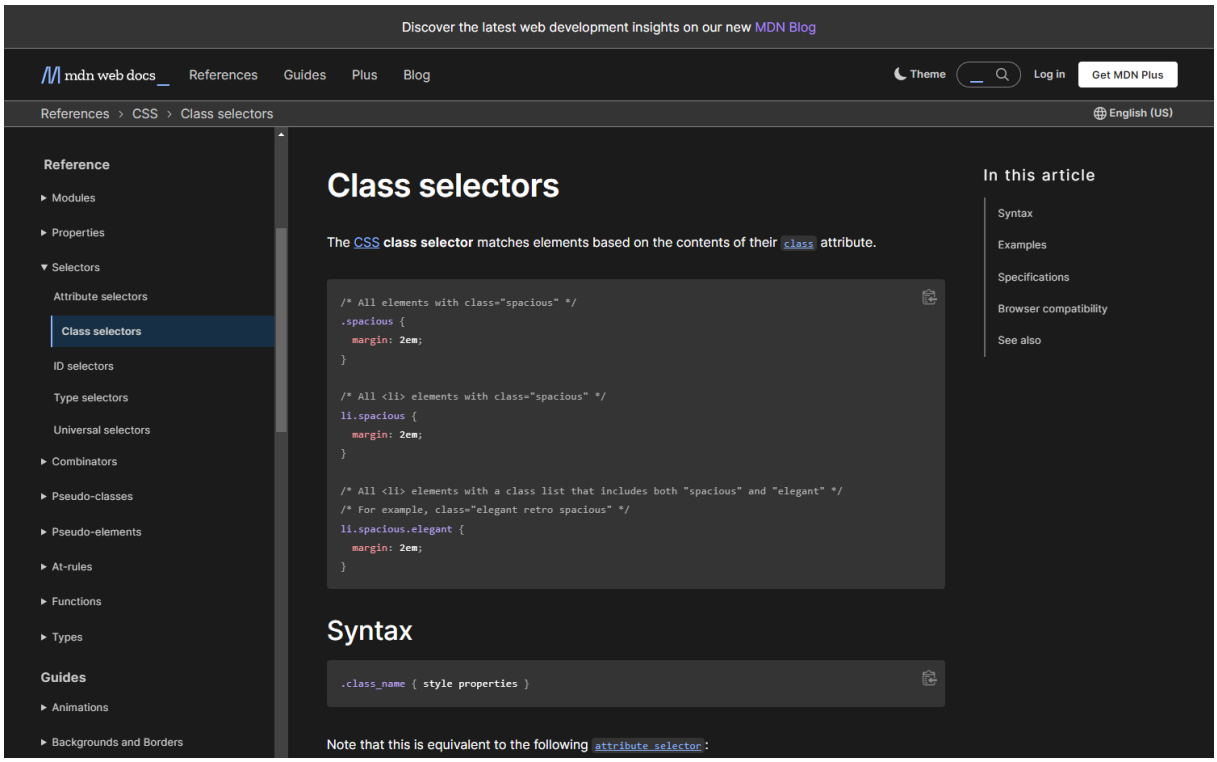

Figure 19: A screenshot from the MDN documentation site.

6.1.2 Choosing the Tech Stack

When selecting a tech stack, it is crucial to weigh the options and determine which one is the most suitable for your project. Familiarity with various stacks and frameworks can prove beneficial as it can serve as the determining factor when faced with multiple options.

Table 7 showcases the frameworks that the team evaluated before beginning the development of the dissemination website. While some of these frameworks were familiar to us, such as React, Docusaurus, and Next.js, others were alternative options that none of us had prior experience working with.

Table 7: Frameworks considered for the project

Name	**Description**
React	A JavaScript library for building user interfaces.
Docusaurus	A React-based modern static website generator that makes it easy to build documentation websites.
Next.js	A React-based web application framework that enables server-side rendering and static site generation.
Vue.js	A progressive JavaScript framework for building user interfaces.
Nuxt.js	A Vue.js-based framework for building server-side rendered (SSR) applications.
Sveltekit	A framework for building web applications using the Svelte compiler.
Angular	A TypeScript-based open-source web application framework.

One of the crucial lessons from similar guidelines is the ability to always keep our Sustainable Web Design Guidelines up-to-date. Given the fast pace of change in web development, it was important to choose a system that could keep up with the evolving technology and practices. After considering two options, we ultimately decided to use Markdown instead of a CMS. This approach enables static content generation, which reduces the amount of bandwidth required for the user to render the page. In contrast, using a CMS would require the user to request new information from an external database, adding more computational overhead and traffic to the website rendering process.

A core component of our tech stack is the inclusion of a component library, also known as a UI component library. Such libraries consist of several reusable elements for building user interfaces, such as buttons, cards, and navigation, which ensures consistency and efficiency during the design process [75]. As component libraries offer pre-built components, it is easier to maintain a unified design language and speed up the development process. Additionally, these

libraries provide utility classes, which are ready-to-use CSS classes that make it possible to apply specific styles and functionalities to elements without writing custom CSS. We evaluated several component libraries to be used for the styling of the website which are listed in Table 8.

Table 8: Component libraries considered for the project

Name	Description
DaisyUI	A utility-first CSS framework designed for Tailwind CSS. It offers a collection of pre-styled components and utility classes that enable developers to quickly create visually appealing and responsive user interfaces.
Flowbite	A modern CSS framework that provides ready-to-use components and utility classes for building responsive web interfaces. It has a focus on simplicity and performance and offers a versatile set of customizable components and styling utilities.
Material UI	A CSS framework featuring a wide range of pre-built components and styling utilities, inspired by Google's Material Design. With a focus on usability and aesthetics, Material-UI provides developers with ready-to-use UI elements, making it easier to create visually appealing and responsive web interfaces.
Bootstrap	A CSS framework that provides a comprehensive set of responsive components, CSS classes, and JavaScript plugins. Bootstrap includes a powerful grid system, enabling easier development of responsive layouts.

6.1.3 Developing the Website

Our team's first choice for disseminating the guidelines was to utilize Docusaurus, a highly adaptable static-site generator that simplifies content management using Markdown[14]. However, as we added more components and customized the styling, it became apparent that this approach required more time and resources than initially anticipated. Furthermore, we realized that by relying on an existing solution, we would have less control over the sustainability of our solution. The additional workload of fine-tuning Docusaurus to meet our requirements outweighed the benefits of using an existing solution, prompting us to design a custom solution from scratch.

After a brief discussion, the group decided to use Next.js for, among other things, its serverless capabilities and our familiarity with the framework. To accelerate the development process, we opted to use Tailwind[15], an open-source CSS framework, to quickly style and format the website, along with DaisyUI[16], an open-source Tailwind plugin, which offers pre-styled com-

[14] Markup language that is used with plain text to add formatting elements (headings, bulleted lists, URLs) to plain text without the use of a formal text editor or the use of HTML tags

[15] An open-source CSS framework: https://tailwindcss.com/

[16] An open-source Tailwind CSS Component Library: https://daisyui.com/

ponents, resulting in an aesthetically pleasing and accessible website with minimal effort. This decision allowed us to allocate more time and attention to the guidelines themselves. Although we made some tweaks to adjust DaisyUI to our preferences, such as new themes for light- and dark modes, we mostly relied on the default DaisyUI styling. Even though we do not primarily design for mobile as outlined in the Scope section, the default styling of DaisyUI supports responsive styling out of the box.

To put our available resources to good use and provide a refined experience, the decision was made to exclusively develop the website in dark mode. This was done to take advantage of the energy efficiency that dark mode provides, particularly on OLED screens [76]. Additionally, while it is not a requirement for WCAG compliance, the Atkinson Hyperlegible[17] font was chosen to ensure the accessibility and legibility of the website's content. The font was created by the Braille Institute of America with the objective of enhancing legibility and comprehension for individuals with diverse visual abilities [77].

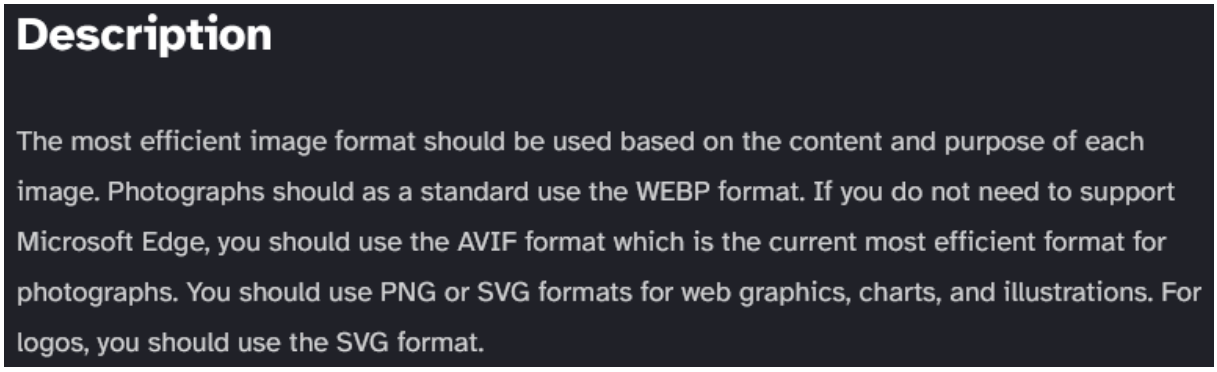

Figure 20: An example of Atkinson Hyperlegible typeface, on the dissemination website.

GitHub[18] was chosen as the primary platform for storing, tracking, and collaborating while developing the website. GitHub provides a powerful version control system, that allowed for easy tracking and changing of the code. GitHub, powered by Git, allows developers to change and make progress on the code on different branches. This contributes to simplifying the work progress and simultaneous development of different parts of the code. This was also an efficient way to collaborate, as it provides tools for code review, where members could review the changes made before merging the code into the main branch of the project. Additionally, GitHub and Git are highly integrated into Visual Studio Code, which is our choice of IDE[19]. The main

[17] A typeface with a focus on readability: https://brailleinstitute.org/freefont
[18] A web-based platform for version control and collaborative software development: https://GitHub.com/
[19] Integrated development environment

contribution of GitHub is that it provides an online service that stores the code, ensuring changes and progress are not accidentally lost. Finally, GitHub provides tools for issue tracking, which we used to gain an overview of the development progress.

By utilizing GitHub's Project feature, we can seamlessly create, assign, and track website development-related issues. The issues are categorized into a Kanban board with "To Do", "In Development", and "Done" sections. This feature enables each team member to effortlessly keep track of each task's status, its assigned member, and its expected completion date.

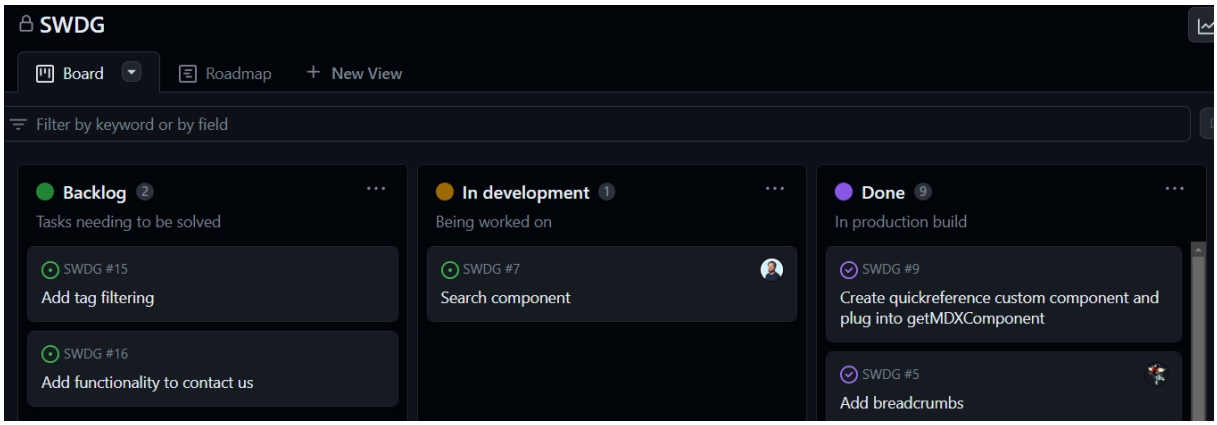

Figure 21: A screenshot from the GitHub Project Board.

6.1.4 Developing With Sustainability in Mind

While developing the website, following sustainability practices was highly prioritized at all times. By already being familiar with the Sustainable Web Design Guidelines, it was easy to pick and choose guidelines that fit the current task at hand, thus making it easy to develop a website with great results from sustainable measurement tools, such as Ecograder[20] and Website Carbon Calculator[21].

Measuring the sustainability of websites is a difficult task, especially when considering all the factors that affect the carbon emissions of the website. Despite this, several companies have developed tools that give an estimation of how much carbon a website emits, and how this impacts the environment. To measure our website, we picked out two tools developed by renowned sustainability-focused companies: Ecograder, developed by Mightybytes, and Website Carbon Calculator, developed by Wholegrain Digital. As mentioned in the Advocates of Sustainable Web section, Mightybytes, and Wholegrain Digital are industry-leading companies, which is

[20] A tool that estimates carbon emissions of websites: https://ecograder.com/
[21] A tool that estimates carbon emissions of websites: https://www.websitecarbon.com/

part of why we chose to use their tools. Their tools also use up-to-date methods for estimating carbon emissions [78].

As mentioned in the previous section Developing the Website, it was decided to use Next.js as the framework for the website. By utilizing Next.js' optimization techniques and unique features, we gained full control over the performance and general behavior of the website. Having full control also meant we could implement our own guidelines with ease.

Next.js is an open-source framework based on React, which includes features such as statically generated content, meaning the content is pre-rendered and the server does not need to generate content on the fly. Generating content on the fly may potentially lead to a delay in load times and higher energy consumption, depending on the nature and variability of the data. In this case, since the content of the website does not frequently change, it was decided to use statically generated content. Another feature we utilize from Next.js is the ability to host our website through Function as a Service (FaaS, also known as serverless architecture). By utilizing serverless architecture, we allow our application to "spin down" when not in use, meaning we save resources that otherwise would be spent keeping the application active. This results in less energy consumption, at the cost of an increased response time when the application has spun down [79].

As suggested by the Sustainable Web Design Guideline 3.4 "Font Subsetting", the website utilizes a feature from Next.js, called font-subsetting, which involves compressing the font to only include the character glyphs set by the developer. This process aims to remove any unused characters, resulting in a lighter font that loads faster and increases the website's overall loading speed and performance [80].

Listing 1: Code showcasing how the website implements font optimization

```
1 import { Atkinson_Hyperlegible } from "next/font/google";
2
3 const atkinsonHyperlegible = Atkinson_Hyperlegible({
4   subsets: ["latin"],
5   weight: ["400", "700"],
6 });
```

The Sustainable Web Design Guideline 1.1 "Compressing Images" suggests avoiding the usage of images, if the images do not improve legibility, and utilizing image optimization where images

are present. The website avoids images as much as possible and, where images are present, implements image optimization through Next.js' built-in image optimizer. The image optimizer resizes and compresses images to the optimal resolution for the device's viewport width. While doing so, it maintains the original aspect ratio of the image and formats the image to the lightest file format supported by the browser. The server only optimizes images for device resolutions it has not previously encountered, and caches the optimized images for future use, reducing the need for repeated optimization for users with the same resolution. The website utilizes this and sets the quality parameter for all images equal to the default value of 75%, which compresses the images up to 75% of the original quality, resulting in faster load times. "Width" and "Height" parameters are also set to prevent Cumulative Layout Shifts (CLS) from happening while the image is loading [81]. CLS occurs when elements have been shifted after initially being rendered by the DOM [82].

Listing 2: A code example of how the website implements image optimization

```
<Image
  src={logo}
  width={64}
  height={64}
  className="h-8 w-auto"
  alt="website logo depicting a planet with smiling eyes and mouth"
/>
```

When building for production, Next.js automatically performs techniques that improve the overall performance of the website. It starts with removing unnecessary code formatting and comments without changing the functionality of the code. This action is called code compression, or "Minifying", and is commonly used in web development [83]. The website utilizes this, in accordance with the Sustainable Web Design Guideline 5.6 "Compression". Upon building the website, Next.js also merges the files containing code into larger "bundles" (or "packages"), which reduces the number of requests the browser makes to the server [84]. Finally, Next.js performs "Code Splitting", a technique used to divide the website's bundle into smaller chunks, each required by an entry point [85]. All of these techniques share a common goal of decreasing the total page weight of the website, making it load faster, and perform better.

As mentioned earlier, the website utilizes statically generated content, as suggested by the Sustainable Web Design Guideline 5.3 "Static Solutions", along with client-side rendering. Nor-

mally, in a standard React application, the client receives an empty HTML shell, which is populated with elements based on instructions sent from the server. These instructions are written in a JavaScript format and instruct the browser on how to construct the user interface [86]. However, as the website is serving static content, the user interface is already defined and the browser does not follow any instructions from the server. The only cases where the browser does construct the user interface is when performing several interactive actions. Actions, such as generating a custom checklist using the interactive checklist tool, are only performed on the client and are not replicated by the server. This means that any changes made on the client are not mirrored to the server, resulting in a hydration difference. Hydration difference refers to a difference in what the server sends to the client, and what the client sees in their browser. We mitigate these hydration differences by allowing specific components to be modified by the client, resulting in client-side rendering [87].

To decrease the load time of the website, it utilizes a strategy called lazy loading, as suggested by the Sustainable Web Design Guideline 5.1 ”Lazy Loading”. Lazy loading is used to identify elements that are less important for the initial load of the webpage and decide when these elements should be loaded. A common example of lazy loading is only loading the content of an element when the content is scrolled into view [88]. The website utilizes this wherever images are present, such as on the About page, and this strategy is handled automatically by Next.js [81]. The images will not be requested by the browser until they are scrolled into view, making the page load faster.

6.1.5 Deployment

Deploying the website meant finding a provider that utilizes renewable energy, as well as being located nearby the majority of the users of the website, as the Sustainable Web Design Guideline 6.1 ”Green Hosting” suggests. Due to the constraints of our budget and the lack of available free hosting providers that use renewable energy, we ultimately opted to use serverless hosting as the best available free option, as discussed in the Developing With Sustainability in Mind section.

Of the available serverless providers, we ultimately chose Vercel due to their focus on architectural efficiency, as well as being the primary developer for Next.js, the framework chosen. While Vercel does not explicitly offer green energy hosting because of their reliance on multi-

ple cloud providers, they have however committed to minimizing the environmental impact of their infrastructure [89]. To further reduce the environmental impact of sustainableweb.net, we utilized a Content Delivery Network (CDN) provided by CloudFlare, due to its extensive geographical coverage and commitment to using 100% renewable energy by 2025 [90]. By caching the website's content and delivering it from servers located closer to the user, the CDN helps to minimize the website's carbon footprint.

As mentioned in the Developing the Website section, GitHub was chosen as our main platform for collaboration, when developing the website. Vercel offers integration with GitHub, and our deployment strategy followed that of Continuous Deployment. In Continuous Deployment, the changes made to the solution are automatically deployed to production. Vercel has a built-in auto-deployment feature, which we configured to only deploy when changes were made to the main branch of the GitHub repository. This meant we could work on new features in a development branch, create pull requests from the development branch to the main branch, and implement new features on the website once it has been approved. However, before any new features were merged into the production build, we had to make sure everything functioned and did not break the website. Vercel runs tests, specified by the framework (Next.js), and builds the solution to check for any errors, and to make sure everything is working as intended [91]. Continuous Deployment is an alternative to Continuous Delivery, where almost all steps are identical (code, test, build, deploy), except the last step of deploying to production is done manually. It was decided to use automatic deployment, as this simplified our workflow and allowed us to spend more time further developing the website, and less time managing deployments.

6.1.6 Interactive Checklist Tool

As identified in Study 2: Challenges and Barriers, when implementing accessibility, practitioners prefer using internal tools and checklists over the official guideline website. This proves that practitioners have a need for interactivity as well as a tailor-made resource when following measures to improve their web solutions. To address this challenge, the website has implemented an interactive checklist, available to all visitors.

This is an online, shareable, and interactive tool that lets users pick and choose guidelines, appropriate for their web solution. The checklist generates an algorithmic URL that can be shared with others, or saved for later use. An algorithmic URL means the URL is never random

and follows a strict set of rules when generating. The way we built this algorithm was to combine the ID from every guideline the user selected, into a string, separating the IDs by dashes (”-”), and compressing the string using Google’s Brotli compression algorithm[22]. By doing so, we achieve a very short parameter that can be passed to the URL, while also ensuring that the URL remains legible and optimized for SEO. To review the code utilized, please refer to Appendix G.

Users can choose the guidelines they want to implement and exclude the ones that are not relevant to them. This personalization can improve the user experience and make the guidelines easier to track and implement. Integrating the tool into the website gives users access to up-to-date information from the website’s guidelines, ensuring they follow the latest measures and methodologies.

The checklist simplifies the process of implementing Sustainable Web Design measures for teams, by allowing them to share- and collaborate on the checklists the teams create using the tool. The checklist groups guidelines into categories, ensuring a structured framework that is easy to follow.

6.2 Results

The section provides the results of designing and developing the wireframes and the Sustainable Web Design Guidelines website. It includes screenshots of various wireframes made using Microsoft Whiteboard and Figma, which were used to develop the website’s information architecture and design. The section also describes the purpose, features, and different pages of the final website by providing screenshots of each page and a brief overview of what users can expect to find on each page. The estimated carbon emissions for the website are also presented, with an Ecograder score of 99/100.

6.2.1 Wireframe

The following figures are screenshots of various wireframes made using Microsoft Whiteboard and Figma, to develop the website’s information architecture and design. The first wireframe depicts the first sketch made early in the thesis, which was used to discuss the overall structure of the website.

[22] A compression algorithm developed by Google: https://GitHub.com/google/brotli

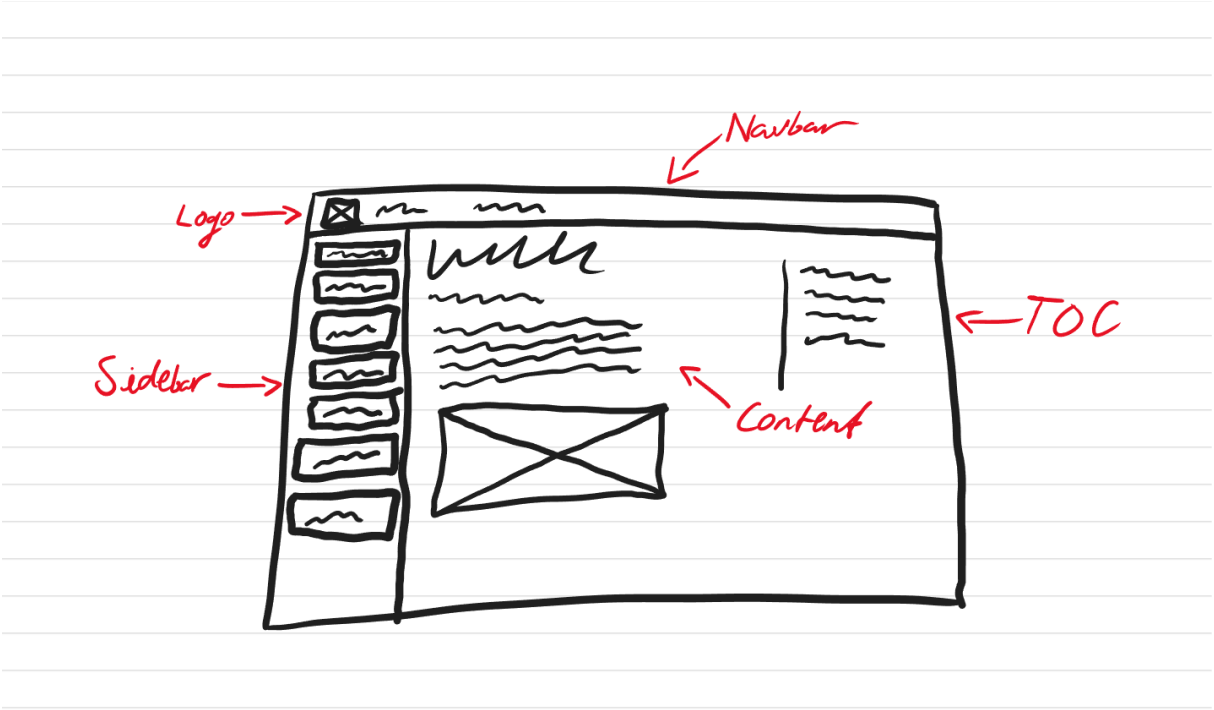

Figure 22: An image of the low-fidelity wireframe for the website.

The second wireframe depicts the wireframe used to develop and design the interactive checklist section for users to choose the guidelines they want to incorporate in their process and share.

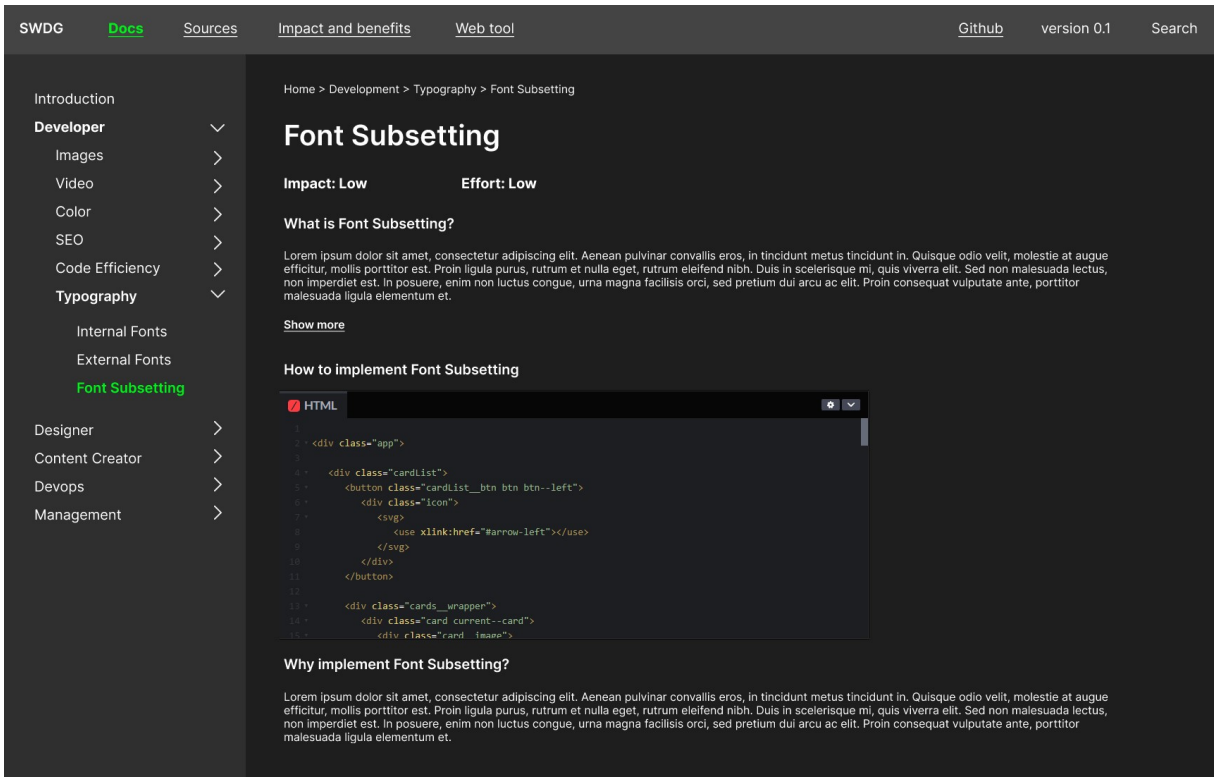

Figure 23: A screenshot of the high-fidelity wireframe depicting the homepage.

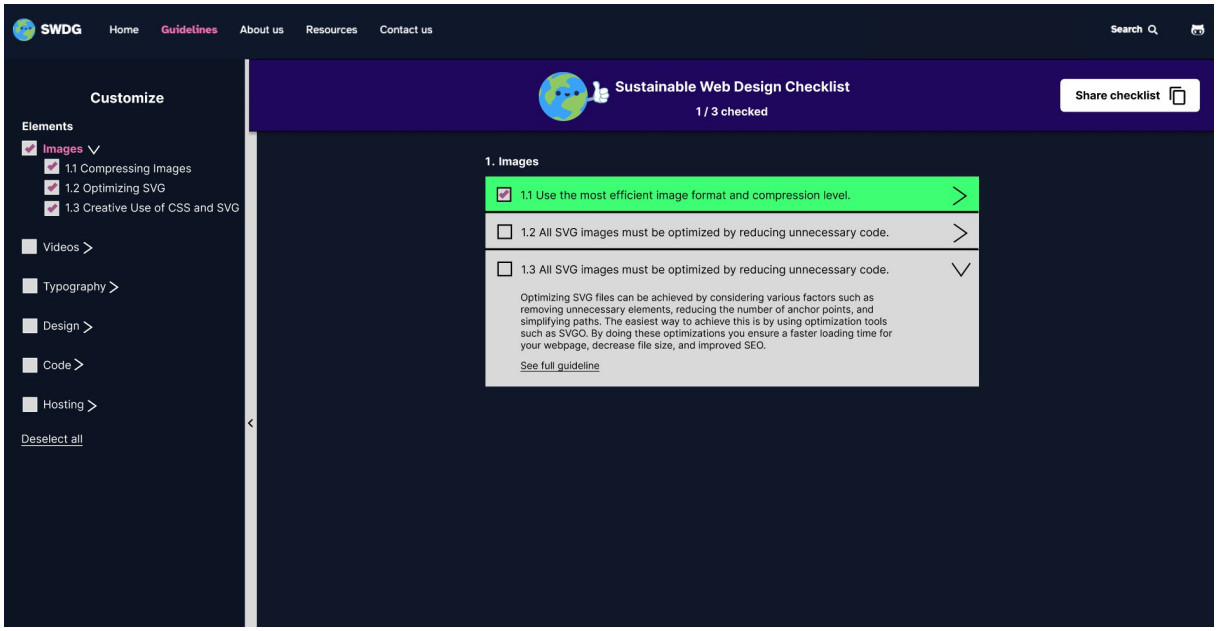

Figure 24: A screenshot of the high-fidelity wireframe depicting the interactive checklist.

The last screenshot from the wireframes used in developing the website is an earlier idea for how to let users choose their wanted guidelines in the interactive checklist tool provided on the website.

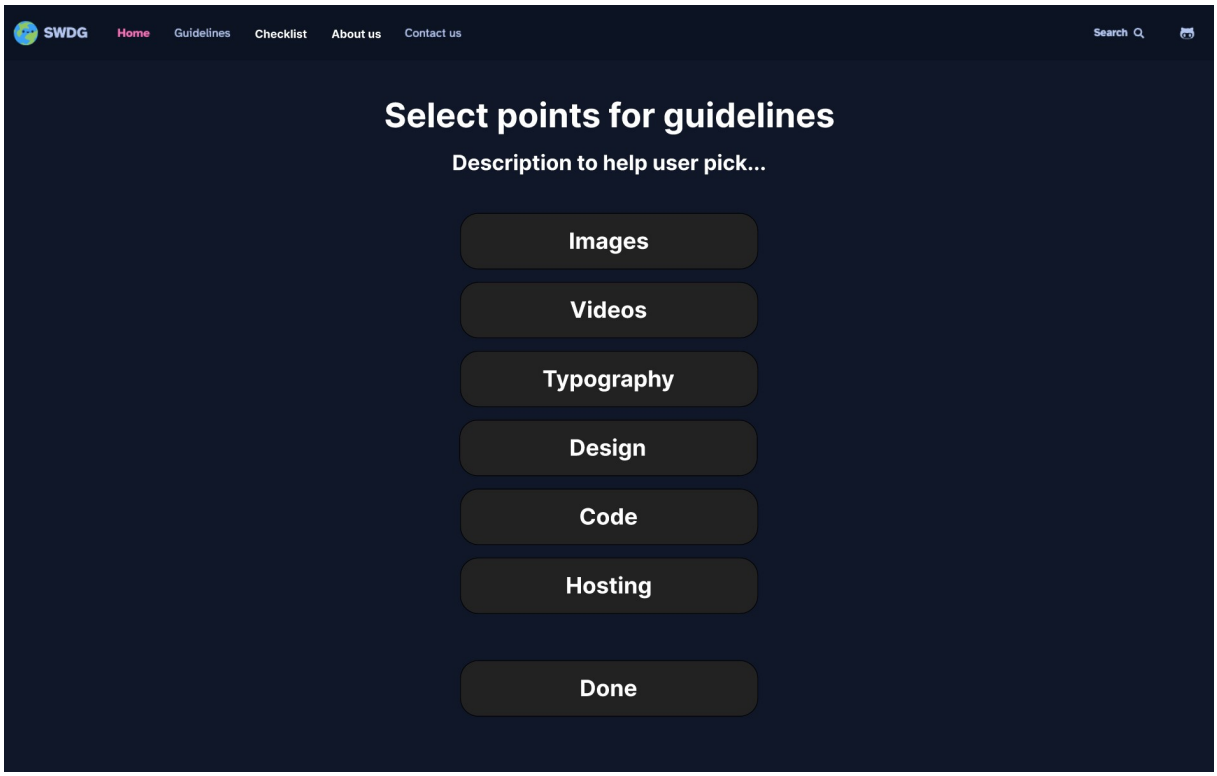

Figure 25: A screenshot of the earlier idea for choosing categories for the interactive tool.

6.2.2 Website

The Sustainable Web Design Guidelines website aims to provide knowledge and tools to empower website developers to create environmentally friendly websites. With separate guidelines on images, videos, typography, design, code, and hosting, the website offers readers comprehensive guidance on Sustainable Web Design practices. The website is built on Sustainable Web Design principles and uses features such as lazy loading, a combination of static site generation and client-side rendering, serverless hosting, code minimization, and code-splitting.

The ”Home” page of the website is used as a landing page and contains a brief introduction to the website, along with our mission, the goal of the website, and how Sustainable Web Design can affect your website. This page features two Call To Action buttons, ”Explore Guidelines” which brings you to the ”Guidelines” page, and ”Create Checklist” to the ”Checklist” page.

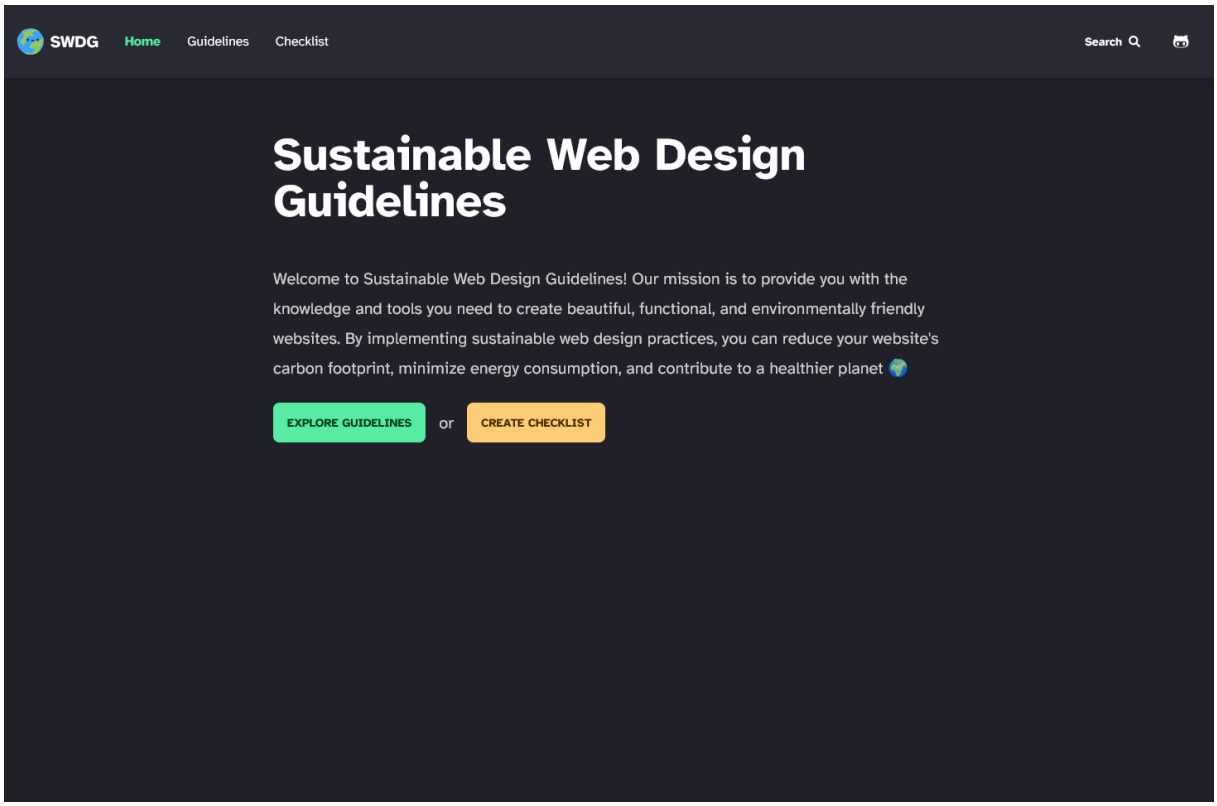

Figure 26: A screenshot of the landing page.

The ”Guidelines” page contains everything you need to know about Sustainable Web Design practices. Our guidelines are written to help all stakeholders in web design to follow sustainable measures when developing web solutions. The guidelines are split into six distinct categories: Images, Videos, Typography, Design, Code, and Hosting. Each category has separate guidelines which teach the reader about how to implement the sustainable measure, why to implement it, and the references used. Every guideline also features a description, and some a ”Quick Reference”, used to quickly give the reader an overview of what the guideline entails.

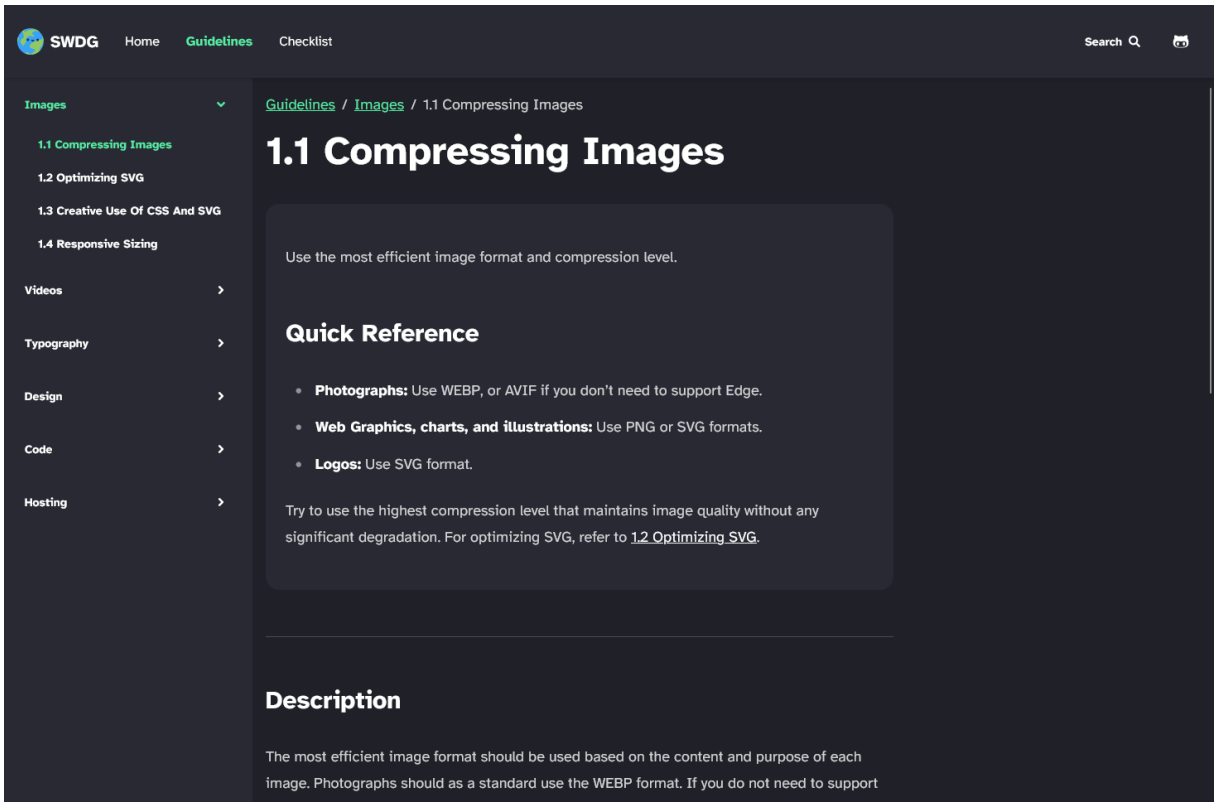

Figure 27: A screenshot of a guide from the guidelines page.

The ”Checklist” page features a tool that helps users create customized checklists based on the categories and guides they select. The checklist generates a list with separate parts for each category, with the respective guides contained inside in a list format. The guides are expandable, allowing the users to quickly read the description of the guide. Users can tick check boxes next to each guide, marking them as finished, and track their progress in implementing sustainable measures while developing. This checklist tool is designed to be simple and easy to use, making it an effective way to ensure that you’re following Sustainable Web Design practices.

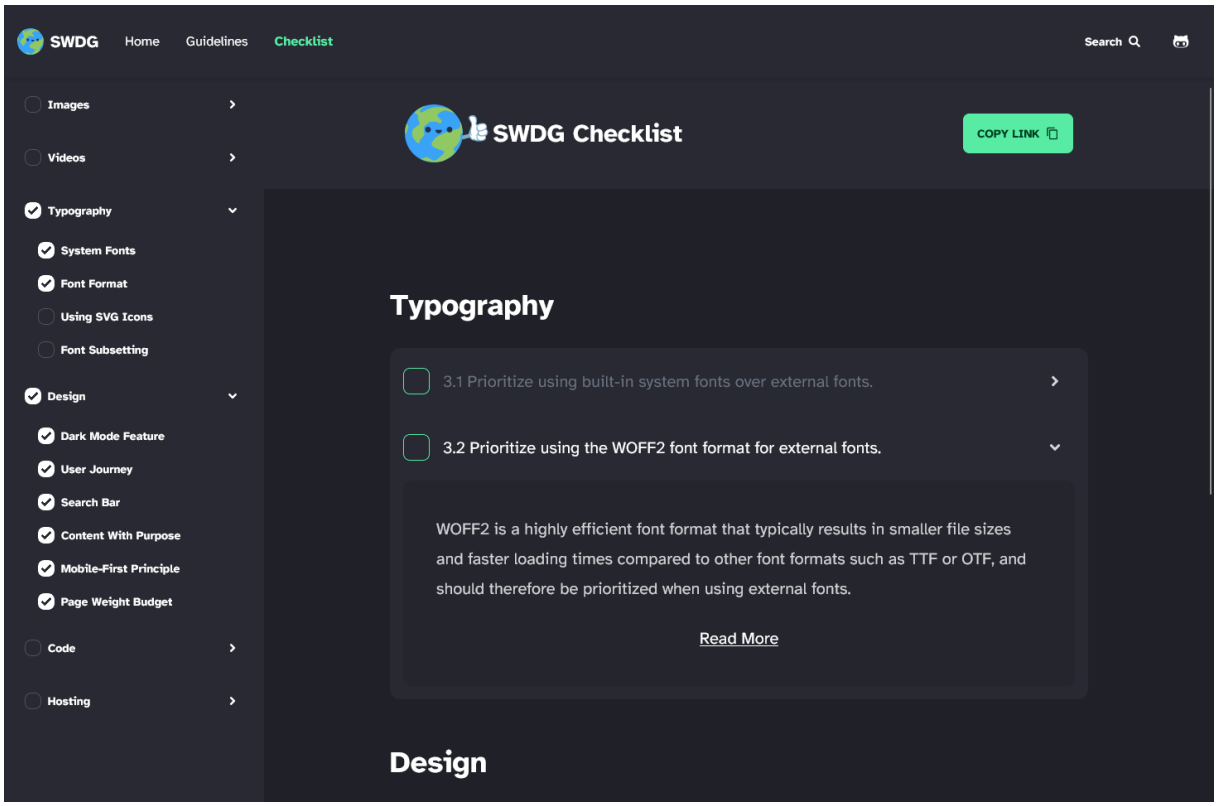

Figure 28: A screenshot of the interactive checklist tool.

The ”About” page gives users the ability to read about the creators of the website and how the project started. It features the following topics: introduction, our story, our team, our mission, our goals, and getting involved. The ”getting involved” section describes how anyone can get involved with improving the guidelines.

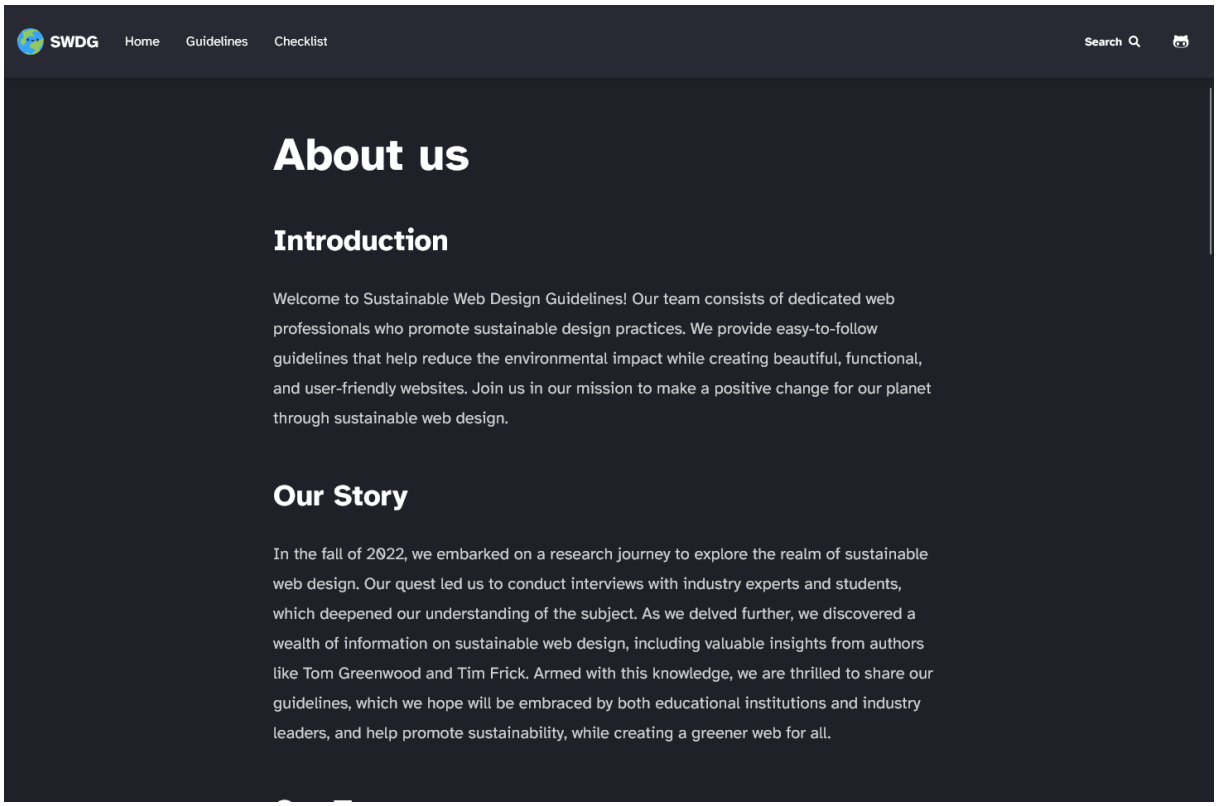

Figure 29: A screenshot of the about page.

The ”Publications” page features all of our publications. The publications are related to Sustainable Web Design and this page gives those interested in learning more a chance to read more. The page features an abstract and a link to Springer per publication.

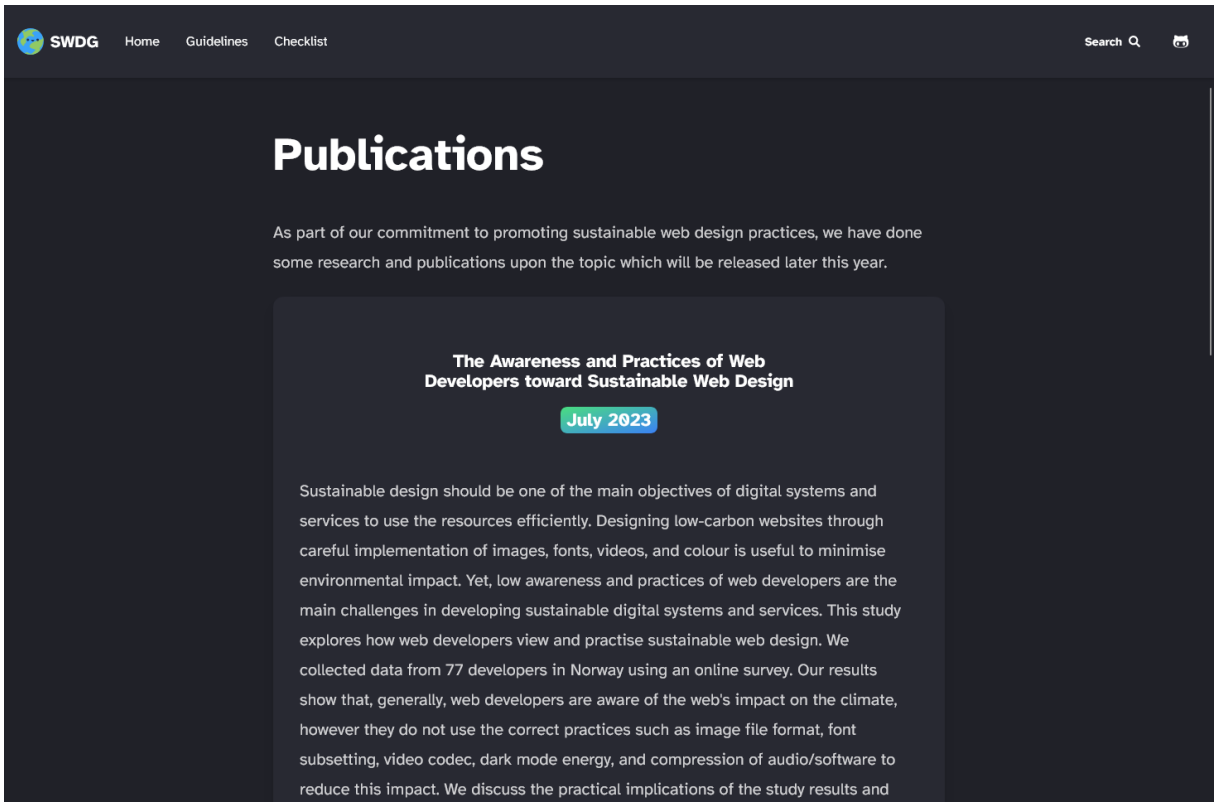

Figure 30: A screenshot of the publications page.

The ”Contact” page allows users to contact us with questions, feedback, or concerns regarding the website and guidelines. It includes a form where the user can state their email, topic, and message.

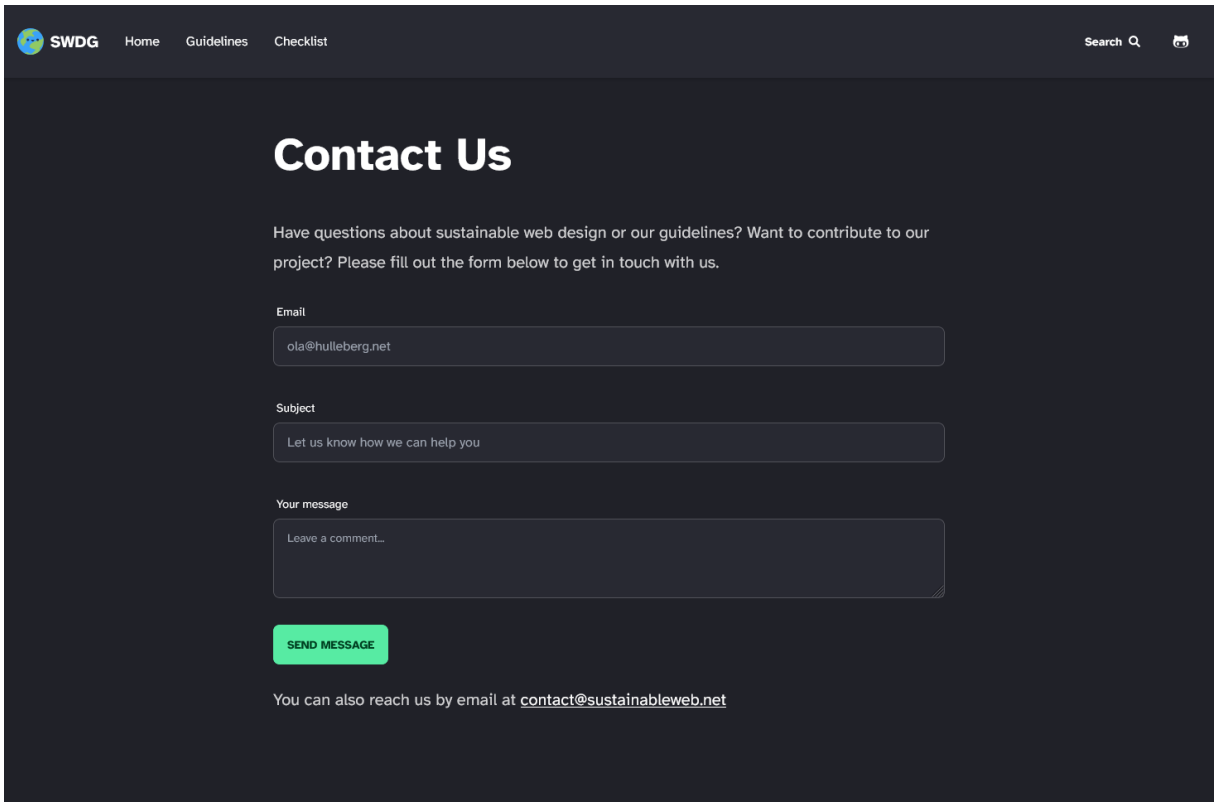

Figure 31: A screenshot of the contact page.

6.2.3 Sustainability Report

This section provides an overview of the sustainability testing results obtained using the online tools Ecograder and Website Carbon Calculator. The testing focused on the three primary pages: Home, Guidelines, and Checklist, as these pages are expected to receive the highest traffic. Additionally, we examined one guideline page to assess the impact of these specific pages.

Website Carbon Calculator: Table 9 presents the findings obtained through the carbon calculations from Website Carbon Calculator. The results indicate that multiple web pages exhibit identical levels of CO2 emissions per visit, with an average emission of approximately 0.235g. Notably, this outcome surpasses the performance of 76% of all the web pages tested with the tool, underscoring a noteworthy achievement in terms of sustainability.

Table 9: Website Carbon Calculator Results

Name	Page	Emissions
Home	sustainableweb.net/index	0.23g
Guidelines	sustainableweb.net/guidelines	0.24g
Compressing Images	sustainableweb.net/guidelines/image/compressing-images	0.24g
Checklist	sustainableweb.net/checklist	0.23g

Ecograder: Table 10 presents the results of carbon calculations carried out using Ecograder. The emissions obtained are slightly higher than those calculated by Website Carbon Calculator, indicating that approximately 0.335g of CO2 is generated per page visit.

Table 10: Ecograder Results

Name	Page	Emissions
Home	sustainableweb.net/index	0.33g
Guidelines	sustainableweb.net/guidelines	0.34g
Compressing Images	sustainableweb.net/guidelines/image/compressing-images	0.34g
Checklist	sustainableweb.net/checklist	0.33g

The comprehensive performance report (see Figure 32), revealed an exceptional score of 99 out of 100 for the homepage. Specifically, the assessment awarded a perfect score of 100 for page weight, 99 for UX design, 100 for green hosting, and 97 for the carbon score. The report emphasized the need for enhancements in page search and accessibility under the UX design category to achieve a perfect score of 100.

Figure 32: A screenshot of the results from sustainableweb.net at Ecograder.

6.3 Conclusion

The design and development of a website dedicated to disseminating our guidelines for Sustainable Web Design is an important final contribution of this thesis. It serves not only as a valuable resource for stakeholders to access our guidelines but also as a practical checklist for implementing them with its separate checklist page. Based on low- and high-fidelity wireframes, we utilized Next.js, Tailwind, and DaisyUI to develop a visually appealing and user-friendly website. Our commitment to sustainability was embedded throughout the development process, ensuring that the website itself adhered to our Sustainable Web Design Guidelines. We validated our efforts in this regard by testing the website using Ecograder and Website Carbon Calculator. The results were highly encouraging, affirming that our sustainable design practices had effectively reduced the environmental impact of the website. We hope the website and its contents will serve as a valuable resource for universities and the industry as a whole to implement sustainable practices for their web solutions.

7 Discussion

In this chapter, we thoroughly examine all the preceding chapters of the bachelor thesis. It is divided into five sections:

1. Research
2. Study 1: Awareness and Practices
3. Study 2: Challenges and Barriers
4. Guidelines and Dissemination
5. Future Work

The Guidelines and Dissemination section includes the guidelines, their dissemination, and their contributions. We have adopted this structure to enhance readability and to provide a clear overview of the progress we have made throughout the semester while working on our thesis.

The thesis contributes to lowering the carbon emissions of the Internet by promoting the importance of Sustainable Web Design through three distinct studies. These studies make contributions to goals 10, 12, and 13 of the United Nations Sustainable Development Goals [29], along with the Paris Agreement of 2015 [92].

Through Study 1: Awareness and Practices, a better understanding of the awareness and practices regarding Sustainable Web Design was obtained. This study contributes by highlighting the current lack of sustainable practices among Norwegian practitioners while showing the practitioners' awareness of sustainable methods. Study 2: Challenges and Barriers investigated the fundamental reasons behind the absence of Sustainable Web Design practices in the industry. The study identified significant obstacles and hindrances that practitioners encounter when trying to implement sustainable measures within their web solutions. These studies together highlight important issues and discuss potential solutions to contribute to the sustainability of the web industry. Additionally, the guidelines will help practitioners create sustainable web solutions. Achieving this goal involves prioritizing minimalism and reducing page weights, resulting in websites that are more hardware-friendly and quicker to load. By enabling access for individuals with less powerful devices and slower internet connections, this approach not only promotes

greater inclusivity but also helps to reduce inequalities in website accessibility across the globe. Thereby contributing towards Sustainable Development Goal 10.

Finally, the development and online publication of Sustainable Web Design Guidelines can promote both Sustainable Development Goals 12 and 13 by ensuring the responsible production of websites. This aligns well with the goal of promoting sustainable production and consumption patterns. Moreover, the guidelines provide practical recommendations on sustainable practices, which can reduce carbon emissions and contribute to the fight against climate change. This, along with our other contributions to the UN's goals, corresponds with the Paris Agreement's goal of limiting global warming and taking urgent action against climate change.

7.1 Research

The apparent lack of research on sustainability within the Web may be attributed to the challenges and barriers identified in Study 2: Challenges and Barriers. As previously established, practitioners in the web industry are aware of sustainability but are reluctant to embrace it in their development processes. The lack of motivation and customer-oriented prioritization may be deduced as the primary contributor to the apparent lack of research in the field. Due to customer-oriented prioritization, the customers decide the requirement of the final product, meaning they choose what to invest in the development process. Customers may not invest in sustainability due to a lack of understanding about its benefits or because it is not considered a priority when compared to other possible investments, such as user satisfaction or Search Engine Optimization. This is also prevalent throughout the different stages of the development process. A quote from a participant in Study 2: Challenges and Barriers supports this, saying that "Customers do not always listen to the experts' advice. Don't always have time to persuade the customer about what is best. Can persuade the customer about what is best, but the customer does not always listen".

Additionally, the lack of knowledge identified among practitioners may also be similar among their customers. This lack of knowledge could impose a presumption that sustainability increases cost and reduces efficiency. However, our background research shows that even if the cost may increase in the development process, sustainable practices can reduce cost in the long run by reducing the cost of storage, computational processes, and transmission. The industry traditionally has focused on providing the best, state-of-the-art digital solution with the most

content. This has meant that sustainability has been neglected to achieve the customer's requirements and success criteria. Companies naturally want to achieve commercial success, which means gaining users of their digital solution and generating profits. These presumptions need to be further researched, to evaluate whether the customer does not prioritize sustainability or they face the same challenges as the practitioners.

In addition to the lack of awareness among stakeholders highlighted in Study 2: Challenges and Barriers, the absence of explicit sustainability goals in Norway's Digitization Strategy for the Public Sector [93] also suggests a potential lack of awareness at the government level. While the strategy emphasizes enhancing online services for improved accessibility and inclusivity, it fails to consider the environmental impact of digital services and the need for corresponding actions in this regard. It is possible that a lack of knowledge and understanding led to the oversight of sustainability as a significant concern during the strategy's formulation. However, it is vital to acknowledge that sustainability must be an integral aspect of any digitization initiatives carried out by governments and other institutions to contribute towards lowering the carbon emissions of the Internet.

Furthermore, the climate crisis has only become more relevant in the last ten years, resulting in the Paris Agreement instigating the climate crisis into reality. This focus appeared at the same time that technology has rapidly evolved along with its energy consumption. Critics of sustainability argue while technology has improved its energy efficiency, the overall energy consumption to keep up with demand is rapidly growing. This means that technology does not sufficiently evolve to alleviate the overall energy consumption that leads to environmental impact. To increase focus on sustainability, addressing the challenges in Study 2: Challenges and Barriers and shifting towards a more minimalist approach and prioritization of sustainability is needed to inspire practitioners and increase research in this field.

As concluded in Study 2: Challenges and Barriers, implementing bottom-up and top-down approaches is vital to ensuring that sustainability is incorporated into the industry. These approaches can have the potential to address the motivational challenges prevalent in the industry and guide the industry's prioritization and decision-making choices toward the minimalist approach discussed above. The top-down and bottom-up approaches differ in terms of their starting point and primary focus. The top-down approach emphasizes high-level planning and decision-making, while the bottom-up approach prioritizes the execution of specific tasks and

the development of in-depth knowledge [94]. Similar approaches have been made to integrate web accessibility, which is why it is highly relevant to compare the regulations and incentives made to ensure web accessibility to use as a baseline for sustainability.

According to [95] on implementing web accessibility policies, social institutions have influenced the design and implementation of web accessibility policies by structuring participation and constraining decision-making in standardization. Non-state actors have played a role in implementing web accessibility policies by supporting standardization and circumventing the role of the State. The institutional setting has influenced the ways in which policy actors respond to the implementation of web accessibility policies, leading to both traditional regulatory requirements and market-based values for social responsibility and profit-making. Policy actors have implemented legal obligations in practice by emphasizing the social norms, values, and procedures of web accessibility and using audit and certification initiatives.

This has, in turn, produced and evolved into current standardization and regulations by national and international bodies of government, for instance, how the European Union and the Norwegian government audit and regulate web accessibility through compliance with Web Content Accessibility Guidelines (WCAG). As previously established, government regulations are one of the primary motivators for implementing web accessibility in the industry, where it is mandatory for practitioners to include accessibility in their development processes. To audit the regulations, governments have the power to monetarily penalize business that does not sufficiently comply with the regulations, until they accomplish it. Similar regulations and policies could highly benefit to increase motivation and prioritization of Sustainable Web Design in the industry.

To facilitate bottom-up approaches, practitioners that directly work in the development process need to increase their leverage of technical in-depth knowledge and understanding in decision-making and planning for digital solutions. This means shifting from a customer-oriented approach to a more combined approach where the practitioners and customers plan and make decisions, emphasizing only adding necessary requirements to achieve the determined outcome. This results in lowering the environmental impact of the digital product.

Throughout this thesis, we have observed that there are difficulties in calculating the CO2 and CO2e emissions of the Web. This results in differences and uncertainties in evaluating the true environmental impact of the Internet. Calculating the emissions caused by the Web is a complex

task, where several factors need to be evaluated and considered. As the Web is a decentralized infrastructure, it involves vast amounts of servers, data centers, and networks that all consume different sources of energy. Additionally, the type of content, user behavior, and the type of energy consumed by the different devices all need to be considered in these calculations.

In the literature review and research made during this thesis, we have used calculations from several authors and experts in the field, such as Gerry McGovern, Tim Frick, Tom Greenwood, and other sources. However, it is crucial to note that all these authors have different methods of calculating, and the data available at the time of their calculations may differ. For the scope of this thesis, calculations from experts in the field will be used as estimations of the environmental impact of the Web and websites, to underscore the importance of researching and contributing to this field of web design. Therefore, this thesis will not provide any calculations made directly to this thesis, other than the sustainability reports of the website disseminating the guidelines. Future work and research within this field should therefore also focus on standardizing and establishing improved methods to get more accurate estimations to address the environmental impact of the Web and the Internet.

7.2 Study 1: Awareness and Practices

This study examines web developers' current practices and awareness of Sustainable Web Design. The data from 77 web developers indicate that while developers are generally aware of the web's impact on the environment, they are not consistently using sustainable practices to reduce their impact.

On an average website, images contribute the most to carbon emissions [12]. The environment can be significantly impacted by selecting the appropriate image format. Unfortunately, our comparisons show that many practitioners still opt for less sustainable formats like JPEG and PNG instead of more eco-friendly options such as AVIF or WEBP. However, selecting the most sustainable format might not always be straightforward. Broz [96] conducted a similar study and discovered that in specific use cases, such as text images, PNG had a better quality-to-size ratio than both WEBP and AVIF. Nonetheless, our comparison results and Broz's findings agree that AVIF and WEBP are the most effective formats for images.

Storing and transferring data create costs and expenses, both in terms of bandwidth and storage. AVIF and WEBP are the most efficient image formats for general use [96], and develop-

ers should ideally be using these formats to save businesses money by replacing less efficient formats. However, despite this, data indicates that many developers still use less efficient formats. In cases where support for Microsoft Edge is required, we recommend using WEBP as the second-best option, due to its current lack of support for AVIF [97]. In a perfect scenario, AVIF would be universally supported by all clients and browsers. Although our comparison results show that AVIF outperforms SVG and SVGZ, it is essential to consider the advantages of vector formats such as scalability and, in certain cases, smaller sizes compared to rasterized images based on the display resolution. Additionally, all the online compression tools tested [98, 99, 100, 101] transcoded the input video file with the H264 codec by default, which in our test was the worst codec for saving bandwidth. From this, we might assume that developers who are using online compression tools, without changing any settings, are not compressing files to an optimal degree. There are however easily implementable methods to mitigate unnecessary data transfer, like page caching, file compression [12], and GZIP compression for websites [102]. Despite this, there is a lot of room for improvement in the efficient use of sustainable design practices and resources for websites and web-related software.

When distributing video content online, the choice of video container format is often less crucial than you may think. Although there are differences between the container formats in what codecs and features they support, simply changing the container format does not often save much disk space or any at all. While rendering software may display a notable variance between video formats, it is most likely the software itself automatically selects a different video codec per container as preset rules. As highlighted by the participants in Study 1, MP4 is the most commonly used video container format. Therefore, in the guidelines, we recommend MP4 because of its wide support. It offers efficient video and audio codecs, as well as accessible options. However, the true space-saving method, as indicated in our study, is the choice of video codec. Our research showed that AV1, the newest codec, offered the most space-efficient alternative and provided significant quality improvements per MB of video.

Most of the questionnaire participants indicated that using a dark mode for websites would be the most energy-saving approach. However, only a single participant reported always incorporating this feature, and a very small percentage reported implementing it frequently. The low implementation rate could be attributed to developers finding it burdensome to include such a feature, despite its ease of implementation with just a few lines of code [103]. Besides the sustainability aspect, a survey by Spiceworks [104] found that a majority of website users prefer to

have a dark mode option available and utilize it on multiple devices.

Design decisions might be a factor that is a potential cause for the high usage of external fonts. Designers, companies, and product owners often have styles, policies, and expectations connected to their branding and companies, that may include or exclude certain fonts that the companies use. This may be to establish a recognizable brand. Therefore, using system fonts from a designer's perspective might be less valuable, or recognizable to users reading the websites.

With a Sustainable Web Design approach, all stakeholders involved in web design including developers, designers, DevOps, managers, companies, communities, and government can contribute to creating a more sustainable online world. One way to achieve this is by implementing sustainable design principles into governmental policies and regulations. This would hold the web design industry accountable to sustainability standards, much like the Norwegian government enforces adherence to WCAG [105]. As discussed in the research paper accepted by HCI International, a potential solution was the development of guidelines similar to WCAG, for all stakeholders to follow. This laid the groundwork needed to develop Sustainable Web Design Guidelines. Moreover, education and awareness campaigns were discussed as playing a crucial role in raising awareness about sustainable design methods and encouraging their adoption in the industry.

7.3 Study 2: Challenges and Barriers

The second study focused on uncovering the challenges and barriers to implementing Sustainable Web Design. Participants identified a lack of information and guidelines as the most significant obstacle to implementing sustainable practices. This finding is consistent with previous research [106] that found that practitioners generally understand sustainability, but may lack specific knowledge related to sustainable software engineering. One case study [48] suggested that offering clear guidelines could help lower barriers to sustainability in software engineering. To address this issue, the study recommends creating guidelines that are easy to understand and provide relevant information for the industry to develop sustainable solutions, similar to the guidelines for web accessibility that have been successful in the past. These sustainability guidelines could help lower the barriers to implementing sustainable practices in web design.

As opposed to the findings of Study 1, the results of Study 2 indicate that while the majority

of participants showed some familiarity with sustainable development practices, their understanding of sustainability within web development was limited. To address this issue, the study proposes the implementation of standardized guidelines for sustainable design, which could potentially help overcome comprehension barriers. However, the existence of such guidelines does not guarantee the resolution of comprehension challenges, as demonstrated by the experience with web accessibility guidelines, which were reported to be tedious and difficult to implement. This finding is consistent with previous research [107, 108], which has noted the challenge of achieving web accessibility due to the complexity of existing guidelines. Despite the potential limitations of guidelines alone, they remain an essential component of achieving sustainable and accessible digital solutions. However, they should be supplemented by other measures such as awareness-raising campaigns, training programs, and legal regulations, using both top-down and bottom-up approaches to ensure the effectiveness of guidelines and promote a deeper understanding and implementation of sustainable design practices.

Incorporating sustainable practices in web design poses various challenges, one of which is the inadequate prioritization and motivation of customers within the industry. Low customer prioritization could stem from a lack of knowledge and awareness, which results in a preference for customer-oriented requirements over sustainable development practices. Moreover, some customers may perceive sustainability as an additional cost instead of a cost-saving measure, despite its potential to reduce energy consumption and save money over the long haul [14, 39]. Previous research has cited time constraints, lack of training, and cost constraints as the key barriers to prioritizing web accessibility [51]. However, our interviews uncovered a different trend, revealing that accessibility was given the highest priority while sustainability was deemed the least important area. To increase motivation and prioritization, enforcing Sustainable Web Design guidelines via legal regulations, as with accessibility guidelines in some countries, may prove to be a viable solution [51]. This would provide practitioners with a stronger argument to convince their colleagues and customers about the importance of sustainability, promoting sustainable practices in web development by stimulating the industry's motivation to achieve sustainable solutions.

The inadequate understanding of sustainability among students is highlighted by the absence of comprehensive digital sustainability material in academia, beyond the United Nations' goals, and the inadequate focus on sustainable design education for students [109]. To prepare the upcoming generation of web designers and developers to prioritize sustainability in their work,

academia needs to incorporate more digital design content into their courses and equip practitioners with the necessary knowledge and skills to implement sustainable design practices. By providing guidelines to aspiring practitioners we ensure that they can effectively implement Sustainable Web Design practices.

Introducing sustainability within academia and the university curriculum is crucial for future generations of practitioners. By focusing on sustainable development early in their careers, prospective practitioners can gain the necessary knowledge and comprehension of how their development process impacts the environment. This ensures continuity of sustainable development, by enabling the students to access the same information and understanding as the industry. As different universities increase their focus and implement several initiatives to include sustainability across their university programs, the potential for ensuring a more sustainably focused future grows.

7.4 Guidelines and Dissemination

The development of systematic and informative guidelines that focus on Sustainable Web Design practices can significantly reduce the environmental impact of the web industry. These guidelines aim to provide practitioners with the necessary knowledge and practices to incorporate Sustainable Web Design methods, which are the main contributors to minimizing the environmental impact of websites. These methods mainly focus on reducing the weight of web pages, which involves minimizing the size of data stored and transmitted to load and display the website. The guidelines help to make every part of a website as minimal as possible, compressing everything and retaining only meaningful content that serves the purpose of the website. By implementing these practices, practitioners can actively choose the most environmentally friendly methods.

Reducing page weight not only minimizes the environmental impact but also elevates the focus on code efficiency and website loading speed, which is crucial in today's digital age. If websites take too long to load, customers or users may leave, leading to unnecessary carbon emissions and waste of energy. Therefore, it is essential to consider the speed and page weight of websites to reduce their environmental impact.

To illustrate the effectiveness of these guidelines, consider the example of a business with an unoptimized website that contains hundreds of large images that use less sustainable formats.

Such a business could greatly benefit from using these guidelines to optimize its website. By following the guidelines and compressing the images, using appropriate image sizes and media formats, the business could significantly reduce the cost of storage, computational requirements, transmission, and load time. This optimization would not only benefit the business but also ensure end-user satisfaction.

These guidelines were developed to overcome the challenges of incorporating Sustainable Web Design practices in the current industry. While practitioners had some familiarity with Sustainable Web Design practices, they lacked the necessary knowledge, comprehension, and motivation to include sustainability in their development practices. Furthermore, their decision-making and priorities in the development processes are customer-oriented, meaning the practitioners are heavily influenced by the needs and requirements set by the customer, who are the main stakeholders controlling the money fueling the development process and paying the practitioners' salaries. All these challenges are interconnected and contribute to the lack of sustainability in the web industry, where the knowledge gap was identified as the most important challenge. The Sustainable Web Design Guidelines contribute to overcoming all these challenges to varying degrees, where the most important challenges were prioritized.

Additionally, the practitioners' prior experience working with web accessibility guidelines was a major focal point to design and structure the guidelines. To improve the legibility and adaptability of the guidelines, we primarily adopted a comparative approach to WCAG. We aimed to develop a more refined set of guidelines, by examining the challenges that WCAG has previously addressed and overcome. Our focus on improving the legibility of content and separating concerns in the structure was ultimately driven by the goal of enhancing user satisfaction with the guidelines. By equipping practitioners and other stakeholders with the required tools, knowledge, and comprehension, the industry can improve its development practices, leading to a less environmentally impacting industry overall.

However, there are potential challenges to incorporating the guidelines into the development process of the industry. These challenges include how the guidelines will affect current development processes and how to integrate them into existing digital solutions. It is worth noting that the Web is no longer limited to typical blogs, online stores, and informative websites. There are endless edge cases that cater to the varying needs of the average user, such as streaming services, platforms, software, and other types of services. The guidelines aim to provide the necessary

resources and information to impact as much of the development process and incorporation of sustainable development as possible. However, the guidelines are still in draft form and require further improvement and expansion to increase their adaptability and effectiveness in all development processes.

7.5 Future work

To address the ever-changing and rapidly evolving technology and web industry, the guidelines must continuously be updated with the latest improvements and practices that contribute to reducing the environmental impact of the internet. Although the draft for guidelines needs further improvement and expansion, efforts have been made to make them as timeless as possible. The fact that the industry and technology are constantly evolving and changing, results in necessary updates and improvements of the guidelines to keep up with the technology being made. However, considerations and efforts have been made to make the overall goal for each guideline to be the same regardless of technology. For instance, the guideline ”1.1 Compressing Images” states that practitioners need to use the best available compression technology, to improve the overall page weight. Here, only the methods and detailed explanation of implementation are needed to be updated regularly, as the guideline itself will be relevant regards of the technology.

The effectiveness and adaptability of the guidelines have not been extensively measured. The guidelines were developed with this along with legibility and comprehension in mind, where the latter was prioritized in the quantitative user test of the finished guidelines. By gaining insight into the different issues related to working with WCAG, major prioritization to overcome the issues was made to ensure the guidelines gain better user satisfaction than similar solutions. The user test of the guidelines aimed to gain feedback from practitioners on overall legibility, structure, and comprehension. It is important to note that six out of the eleven practitioners who participated in the user test had prior experience with our work, but only in the context of gaining their insight in Study 2. None of the participants had any prior experience with our guidelines. Further qualitative user testing is vital to accurately measure the effectiveness and adaptability of our guidelines. This qualitative testing should consist of extensive use of the guidelines in real-life scenarios and workshops. Real-life scenarios refer to incorporating the guidelines in both existing digital solutions and throughout a complete development process. This way the effectiveness and adaptability can accurately be measured, to further improve the

guidelines.

During the design phase of the guidelines, discussions took place to categorize the guidelines by role. The purpose was to increase legibility and efficiency in incorporating the guidelines, by limiting the available information displayed, depending on what role the user selected. This approach would allow practitioners to choose their role in the development process, and only the most relevant guidelines would be displayed. However, because this was not considered an essential part of our scope of work, it was decided to instead include it in this section. To determine whether this approach enhances effectiveness, further research will have to be conducted.

Additionally, more interactivity on the website and tools for evaluating the sustainability of digital solutions could further improve the user experience of Sustainable Web Design Guidelines. In the qualitative study, several participants reported interesting ideas to improve their satisfaction experience using both the guidelines and the website. Some of these ideas were more interactive, where users can learn sustainability in a practical way. Through tutorials and interactive coding platforms, similar to CodePen, Codecademy, and W3Schools, users can test out and experiment with sustainable methods directly on our websites. This could prove highly beneficial to increasing knowledge, and comprehension. To increase effectiveness and incorporation even further, evaluation tools can be used to teach practitioners by auditing their digital products. Current evaluation tools for sustainable websites (see Section 2.5.1), like Ecograder, have proven effective in systematically evaluating and comparing websites. However, these tools often fall short in providing comprehensive guidance on the specific areas where improvements are needed. In other words, they lack direct tools that can effectively highlight areas of improvement. Integrating our guidelines into an evaluation tool can simplify incorporation in both existing and new projects, leading to better efficiency and reduced environmental impact.

8 Conclusion

The purpose and goals of this thesis were to contribute to the reduction of carbon emissions of the Web by raising awareness, expanding available research, and providing guidelines for Sustainable Web Design. This goal aligns with the product owner's objective to reduce the environmental impact of the Internet and improve the focus on sustainability in the student curriculum.

By setting a high ambition for the scope of work, a goal was set to develop a holistic approach that resulted in a set of guidelines to assist stakeholders in creating more sustainable websites. The following process was conducted to achieve this: Firstly, we completed the analysis of previously collected data on the awareness and practices among practitioners related to Sustainable Web Design. Based on the conclusions drawn from this study, we continued the research by conducting a qualitative study to identify the challenges and barriers practitioners and prospective practitioners face to incorporating Sustainable Web Design. All this research was used and contributed to our development of comprehensive Sustainable Web Design Guidelines for all stakeholders. Throughout the period of this thesis, we were able to conduct and write two independent research papers. The first research paper, Study 1: Awareness and Practices, has been accepted and will be presented at the HCI conference in Copenhagen in July 2023, while the second study, Study 2: Challenges and Barriers, is in proceedings to be presented at another conference later in 2023. Finally, a website to disseminate our guidelines and studies has been developed to contribute to research and ensure stakeholders can access the guidelines and our work, to incorporate sustainable practices in their development processes.

8.1 Problem Statements

In order to accomplish the objectives of this thesis, three problem statements were tackled to ensure that the guidelines effectively cover all the factors that contribute to the implementation of Sustainable Web Design.

1. To what degree are developers' awareness and practices regarding Sustainable Web Design? Through Study 1: Awareness and Practices, it can be concluded that practitioners in the Norwegian web industry have some level of awareness towards sustainability, and were able to demonstrate some familiarity with Sustainable Web Design practices. How-

ever, the practitioners did not utilize the most environmentally friendly practices in their development processes.

2. What are the current challenges and barriers to implementing Sustainable Web Design? Through Study 2: Challenges and Barriers, it can be concluded that there are several challenges and barriers that practitioners and prospective practitioners face to incorporating Sustainable Web Design. These challenges and barriers are the following, in order of priority: Knowledge gap, customer-oriented prioritization, lack of motivation in the Industry, comprehension challenge, and a lack of sustainability in academia.

3. What are the main practices that should be part of guidelines for Sustainable Web Design? To address the low incorporation of sustainability identified in Study 1: Awareness and Practices and the challenges and barriers identified in Study 2: Challenges and Barriers, a comprehensive set of 29 guidelines were developed. Efforts were made to ensure the legibility and comprehensiveness of the guidelines, by gaining insight into practitioners' experiences with existing resources and guidelines. Therefore, the guidelines are divided into six main categories: Images, Videos, Typography, Design, Code, and Hosting. Each guideline is also separated into distinct sections: Title, Short Description (Optionally: Quick Reference), Description, How to implement, Why, and References. Quantitative user testing was conducted online with several stakeholders, which resulted in overwhelmingly positive feedback.

8.2 Recommendations for the Product Owner

Upon completion of this thesis, we have identified several recommendations for the product owner, the Department of Design at NTNU, to both educate- and expand on research available for sustainability within web design.

1. **Integrate more sustainability in the university curriculum**. In order to ensure that future web designers and developers prioritize sustainability in their work, educational institutions should integrate more digital design content into their courses and provide practitioners with the requisite knowledge and skills to implement sustainable design practices. By furnishing guidelines to prospective practitioners, they would be equipped to incorporate Sustainable Web Design practices throughout their careers.

2. **Measure the effectiveness and adaptability of guidelines in qualitative studies**. It is crucial to conduct additional qualitative user testing to precisely evaluate the efficiency and adaptability of our guidelines. This qualitative testing should involve thorough utilization of the guidelines in practical situations and workshops. Practical situations entail incorporating the guidelines in both established digital solutions and in the course of the entire development process. This approach would enable a precise measurement of the effectiveness and adaptability of the guidelines, thereby facilitating further enhancement.

3. **Improve and expand the guidelines to improve the adaptability for all stakeholders and their needs**. In order to keep up with the constantly evolving technology and web industry, it is necessary to continuously update the guidelines with the latest improvements and practices that help to reduce the environmental impact of the internet. This will increase the guidelines' adaptability to meet all stakeholder's needs and efficiently be better incorporated into their development practices. Future work could also involve exploring the categorization of guidelines by role for practitioners and stakeholders that was discussed during the design phase. This approach could have improved efficiency by displaying only the most relevant guidelines based on the user's chosen role in the development process. Although not included in the current version of the guidelines, this approach should be evaluated in future research to determine its effectiveness.

4. **Create integrated interactive tools to improve comprehension and motivation**. To improve comprehension and motivation, developing automatic tools that evaluate and give suggestions to improve sustainability would be beneficial. Such a tool could be implemented through the use of ESLint[23], which statically analyzes the code to quickly find problems and offer solutions. ESLint can be utilized to hinder committing code that does not follow the ruleset specified, ensuring all code follows sustainable practices. Finally, ESLint gives the developer the exact file and line number the problem is defined at, meaning there will be no confusion as to where the problem persists.

5. **Improve methods to contribute and receive feedback on guidelines**. Maintaining an open-source approach will allow the community to suggest feedback and implement improvements through the use of GitHub or other collaboration sites. GitHub also features forking repositories, meaning a user can create a copy of the repository, implement their

[23] A tool for identifying and reporting on patterns found in ECMAScript/JavaScript code: https://eslint.org/

features, and later perform a pull request into the original repository. This allows the community to work on the original project, without diverting it into multiple separate versions.

In contrast to Wikipedia's user-driven approach to updating and maintaining content, the Sustainable Web Design Guidelines could benefit from a similar system, with designated maintainers responsible for reviewing and approving or disapproving community suggestions. This approach would ensure the site remains current and relevant, while still allowing for community contributions.

To ensure the accuracy and credibility of the content, specific rules should be implemented for approving suggestions from the community. These rules could include requiring that contributions are supported by credible sources and approved by at least two designated maintainers. Additionally, guidelines could be established for the types of content that can be added or updated, such as prohibiting promotional or biased content. It may also be useful to establish a system for addressing and resolving any disputes or disagreements that arise during the review process. By implementing such guidelines, the Sustainable Web Design Guidelines can maintain the trust of its users and continue to provide valuable and reliable information.

8.3 Reducing the Internet's Environmental Impact

Through the publication and submission of two conference papers, we contribute to filling the research gap and inspiring others to embrace a sustainable design approach. Furthermore, the development of 29 guidelines for improving the sustainability of web pages serves as a valuable educational resource for current and future practitioners. These guidelines empower all stakeholders involved in web design to incorporate sustainable practices into their work, thereby effectively reducing the environmental footprint of their digital creations. Moreover, they hold particular importance for universities as they can be used for educating responsible future practitioners. By incorporating these guidelines into their curriculum, universities can equip their students with the necessary skills and mindset to prioritize sustainability in their future professional careers.

8.4 Future Work

The following sections outline some potential directions for future work and research in Sustainable Web Design. By addressing these areas, we can continue to expand our understanding and make progress toward more Sustainable Web Design.

- **W3C proposal**. A W3C proposal may be useful in promoting Sustainable Web Design by increasing its visibility and standardization. By connecting to existing guidelines like WCAG, this proposal could help to raise awareness and encourage the adoption of sustainable design practices. If sustainability were to be integrated into WCAG, it could potentially become a part of existing regulations worldwide, further promoting Sustainable Web Design.

- **Political incentives and initiatives**. To address the lack of motivation and customer-oriented prioritization in the industry, and ensure a top-down, bottom-up approach, proposing political incentives and initiatives could prove beneficial. As observed in regard to web accessibility, political initiatives have been proven to increase incorporation in the industry, as enforced regulations ensure inclusiveness among all users.

- **Technological advancements to improve energy efficiency**. The technology industry is constantly evolving and prioritizing efficiency and processing power. This is encouraging for the environment because increased energy efficiency can help curb the industry's growing energy consumption, particularly as it relates to the Internet. To further support this positive trend, future research efforts should concentrate on enhancing the energy efficiency of technology that drives the Internet's expansion.

- **Make the Web use more renewable energy**. As most of the energy consumed by data centers and servers derives from fossil fuels, a major shift to renewable energy is crucial to reduce the environmental impact of the internet. This is a leading cause of the ecological footprint of the Internet and will become increasingly more important as the demand from users is growing on a yearly basis.

- **Research and establish standards for calculating CO2e emissions of the Internet**. Throughout this thesis, there have been challenges to calculate the environmental impact of the Internet and the Web, as estimations and calculations are complex and are not standardized. This has resulted in differences in methods of calculations and estimations, as

seen in the literature review and research conducted in this thesis. Therefore, future research should emphasize establishing and standardizing methods to accurately estimate the environmental impact of the Internet.

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A Study 1: Awareness Questions

This appendix contains the questions related to the awareness and practices study, as mentioned in Study 1: Awareness and Practices.

Section 1: Demographics

Q1: What age group do you belong to?
(Participant can only choose one)
- 18 – 24
- 25 – 34
- 35 – 44
- 45 – 54
- 55 – 64

Q2: Which title best describes your role?
(Participant can only choose one)
- Student
- Developer: Front-end
- Developer: Full-stack
- Management
- Designer
- DevOps
- System administrator
- Other

Q3: Which title describes you?
(Only asked if the participant chose "other" for the previous question)
(Participant writes their answer in a text field)

Q4: Are you employed in a company?
(Participant can only choose one)
(Only asked if the participant is not a student)
- Yes
- No

Q5: How many employees are there in the company?
(Participant can only choose one)
(Only asked if the participant answered yes to the previous question)
- 1
- 1 – 5
- 5 – 10
- 10 – 20
- 20 – 50
- 50 – 100
- 100 – 1000
- > 1000

Q6: How many years have you worked professionally with development?
(Participant can only choose one)
(Only asked if the participant answered the previous question)
- < 1 year
- 1 – 2 years
- 2 – 5 years
- 5 – 10 years
- 10 – 20 years
- > 20 years

Q7: Which county(s) do you work/study in?
(Participant can choose more than one)

- Agder
- Innlandet
- Møre and Romsdal
- Nordland
- Oslo
- Rogaland
- Vestfold and Telemark
- Troms and Finnmark
- Trøndelag
- Vestland
- Viken
- Outside of Norway

Q8: What is your highest level of education?
(Participant can only choose one)

- High school
- Vocational school
- Bachelor
- Masters
- Doctoral degree

Q9: Is your education related to website development?
(Participant can only choose one)
(Only asked if the participants education is higher than high school)

- Yes
- No

Q10: Which category does your education fall under?
(Only asked if the participant answered "No" for the previous question)
(Participant writes their answer in a text field)

Q11: What purposes do the websites you develop/have developed suit?
(Only asked if the participant is not a student)
(Participant can choose more than one)

- Personal blog / portfolio
- Business services (B2B, B2C)
- Online shopping
- Software
- Social Media
- Internal tools
- Documentation
- Landing page
- Retail
- News
- Game
- Politics / activism
- Streaming service
- Informative
- Other

Q12: What other purposes?

(Only asked if the participant answered "other" on previous question)
(Participant writes their answer in a text field)

Section 2: Practices

Q13: How often do you use the following file types for displaying images on websites?
(Participant must choose between "Never", "Rarely", "Sometimes", "Often" and "Always" for each file format)

- PNG
- JPG/JPEG
- SVG
- GIF
- WEBP
- TIFF
- AVIF
- BMP
- ICO
- APNG
- EPS

Q14: How often do you use these HTML tags to display images?
(Participant must choose between "Never", "Rarely", "Sometimes", "Often" and "Always" for each tag)

- CSS background-styling
- Img
- Svg
- Picture
- Map
- Area

Q15: How often do you use "lazy loading" of images?
(Participant can only choose one)

- Always
- Often
- Sometimes
- Rarely
- Never

Q16: How often do you use external fonts?
(Participant can only choose one)

- Always
- Often
- Sometimes
- Rarely
- Never

Q17: What do you usually compress?
(Participant must choose between "Never", "Rarely", "Sometimes", "Often" and "Always" for each tag)

- Image-files
- Video-files
- Sound-files
- External fonts
- Software

- Code (minimize)

Q18: What software or websites do you use to compress?
(Participant writes their answer in a text field)

Q19: Are you familiar with "font subsetting" and use this?
(Participant can only choose one)

- Yes
- No

Q20: How often do you use video on the websites you develop?
(Participant can only choose one)

- Always
- Often
- Sometimes
- Rarely
- Never

Q21: Which video formats do you use for video display on websites?
(Participant can choose more than one)

- MOV
- MP4
- WMV
- FLV
- MKV
- AVI
- WEBM
- AVCHD
- Other

Q22: What other formats do you use?
(Only asked if the participant answered "Other" for the previous question)
(Participant writes their answer in a text field)

Q23: Do the websites you develop use autoplay?
(Only asked if the participant answered that they use video for their websites)
(Participant can only choose one)

- Always
- Often
- Sometimes
- Rarely
- Never

Q24: Which channels do you use to further develop the necessary skills?
(Participant can choose more than one)

- Course through work
- Video tutorials (YouTube, Vimeo, etc.)
- Podcasts
- Dev blog
- W3Schools
- MDN Web Docs
- Newsletter
- Documentation
- Interactive courses (Codecademy, Udemy, ...)

- Other
- No channels

Q25: What other channels?
(Only asked if the participant answered "Other" for the previous question)
(Participant writes their answer in a text field)

Q26: How often do you offer a choice for the user to be able to choose between dark and light mode?
(Participant can only choose one)

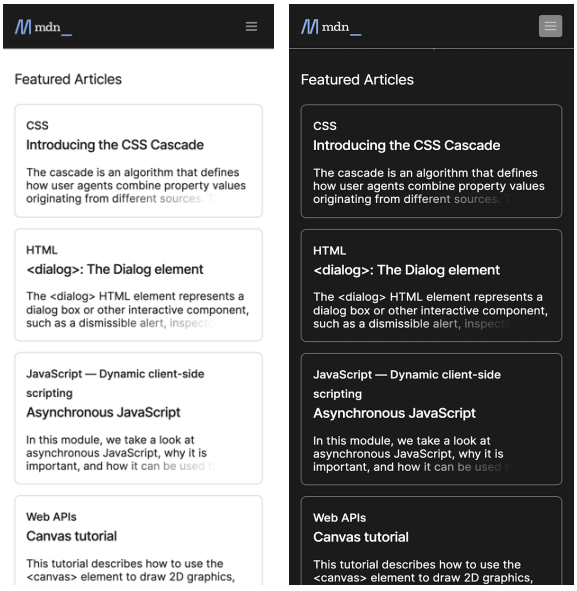
- Always
- Often
- Sometimes
- Rarely
- Never

Q27: How often do you write reusable code?
(Participant can only choose one)

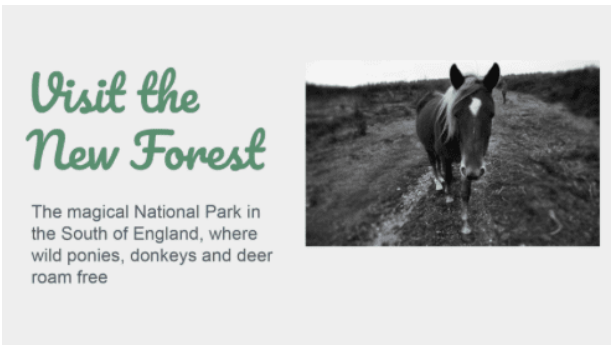
- Always
- Often
- Sometimes
- Rarely
- Never

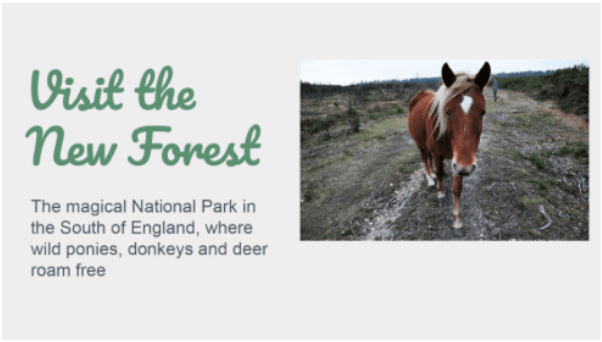
Section 3: Awareness test

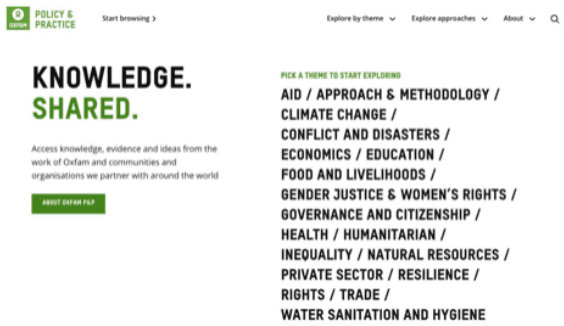
Q28: Based on the images, which version do you think is the most energy efficient on modern mobiles?
(Participant can only choose one)



Q29: Which of the following (four) websites do you think produces the least C02 emissions?
(Participant can only choose one)2







Q30: Which rasterized image format do you think takes up the least space on your hard drive?
(Participant can only choose one)

- JPEG
- PNG
- AVIF
- WEBP
- GIF

Q31: Which fonts do you think are the most energy-saving when loading web pages?
(Participant can only choose one)

- System fonts
- External fonts
- They are equally energy efficient

Q32: To what extent do you think bot traffic affects the energy consumption of websites?
(Participant can only choose one, 1 is to no degree, 5 is to a big degree)

- 1
- 2
- 3
- 4
- 5

Q33: To what extent do you think websites affect the environment through CO2 emissions?
(Participant can only choose one, 1 is to no degree, 5 is to a big degree)

- 1
- 2

- 3
- 4
- 5

B Study 2: Interview Guideline for Practitioners and Prospective Practitioners

This appendix contains the interview guideline used when interviewing practitioners and prospective practitioners, as mentioned in Study 2: Challenges and Barriers.

Interview Guide

1. Background

a. What is your academic background?
b. What is your current occupation and job title?
c. How many years of working experience do you have in development?

2. Development Process

a. How is your development process organized, and do you work in teams?
b. What development methodology do you follow in your current project? (Ex. agile, waterfall)
c. What is the process for adding an image to a website, and do you have any influence on its formatting or creation?
d. Does your team or company have a methodology for deciding what elements to include in the website?
e. Who decides what to include in the applications you build?
f. How would you rank the following in order of importance in your current development process

3. Accessibility and WCAG

a. Do you work with WCAG?
    i. If yes:
        1. How do you apply WCAG, and what is the reason behind your application?
        2. Who validates if something is accessible, and do you systematically make use of tools to assess accessibility?
        3. How have regulations about WCAG affected the way you work?
        4. Do you look up the WCAG guidelines every time or do you look at alternatives?
        5. What is your experience when reading and proofing the guidelines?
    ii. If no:
        1. What is the reason you do not follow WCAG?
        2. Have you any prior experience working with WCAG?

3. What would be essential for making you or your team implement WCAG in the future?

4. Sustainable Design

a. Could you describe sustainability within web design, and how does your company focus on sustainability in general?
b. What is your prior knowledge regarding sustainability, and how do you think accessibility relates to sustainability?
c. Do you personally develop websites or software with sustainability in mind, and what does sustainability within these products mean to you?
d. How many images and videos do your websites normally have, and how do you handle displaying them on the web?
e. Could a guideline as an informational resource be helpful for implementing a sustainable web in the future, and what would you like this resource to have or be like?
f. In what pillar of sustainability do you think web development can contribute the most, and does the company actively try to contribute to any of these pillars?

5. Other

a. Do you focus on being environmentally friendly in other aspects of life?
b. How would you find information regarding web development or design today, and how would you find information regarding sustainable web design?
c. What is necessary for you to consider sustainability within development in the future, and what is necessary for you as a designer or developer to effectively implement sustainable web design?
d. Is there anything else you would like to add that we didn't cover?

C Study 2: Interview Guideline for Academia

This appendix contains the interview guideline used when interviewing academia, as mentioned in Study 2: Challenges and Barriers.

Interview with study program leaders

Norwegian:

1. Hvor lenge har studieprogrammet eksistert?

2. Hvordan er bærekraft integrert i studieprogrammet per i dag, og eventuelt hvor lenge har det vært en del av pensum?

3. Oppfordres studentene til å bruke kunnskapen de tilegner seg i studiet til å fremme bærekraft i samfunnet/i arbeidslivet?

4. Hvilket faglig innhold og utfordringer relatert til bærekraft må studentene forholde seg til?

5. Er det noen planer om å inkludere mer bærekraft for studieprogrammet i fremtiden?

6. Hvilke av de tre søylene for bærekraft tar ditt studieprogram mest hensyn til? Sosialt, Økonomisk eller Miljø. (Evt forklare, forsøker ditt studieprogram å utforme elevene til å ha bærekraftige holdninger innenfor det å skape jobbmuligheter, likestilling, osv)

7. Hvordan ser du for deg at en systematisk retningslinje for å designe bærekraftig kunne blitt brukt i løpet av studieprogrammet? Er det f.eks. noen emner som kunne vært relevant for å introdusere en slik retningslinje per i dag eller burde det bli inkludert i et helt nytt emne?

8. Har du noen ønsker for hvordan retningslinjen burde være oppbygd med tanke på innhold og struktur? Er det noe som er spesielt viktig å ta hensyn til for retningslinjen med tanke på fagfeltet som dine studenter lærer?

9. Hvordan forholder studieprogrammet seg til tilgjengelighet og WCAG?

10. Hvordan synes du personlig at WCAG er å forholde seg til og forstå? Er den vanskelig å lese?

English:

1. How long has the study programme existed?

2. How is sustainability currently integrated into the study programme and, if so, how long has it been part of the curriculum?

3. Are students encouraged to use the knowledge they acquire in the programme to promote sustainability in society/working life?

4. What academic content and challenges related to sustainability do students have to deal with?

5. Are there any plans to include more sustainability in the curriculum in the future?

6. Which of the three pillars of sustainability does your study programme pay the most attention to? Social, Economic or Environmental (if applicable, please explain, does your study programme try to shape students to have sustainable attitudes towards creating job opportunities, gender equality, etc.)

7. How do you imagine that a systematic guideline for designing sustainably could be applied during your study programme? For example, are there any courses that could be relevant for introducing such a guideline currently or should it be included in a completely new course?

8. Do you have any wishes for how the guideline should be structured in terms of content and structure? Is there anything that is particularly important to take into account for the guideline in terms of the subject area that your students are learning?

9. How does the study programme relate to accessibility and WCAG?

10. How do you personally find the WCAG to relate to and understand? Is it difficult to read?

D Sustainable Web Design Guidelines Draft

This appendix contains the draft for the Sustainable Web Design Guidelines, as mentioned in Study 3: Guidelines.

Sustainable Web Design Guidelines (SWDG)

Table of Contents

1. Images
    - 1.1 Compressing Images
    - 1.2 Optimizing SVG
    - 1.3 Creative use of CSS and SVG
    - 1.4 Responsive Sizing
2. Video
    - 2.1 Compressing Videos
    - 2.2 Auto-Playing
    - 2.3 Animations
3. Typography
    - 3.1 System Fonts
    - 3.2 Font Format
    - 3.3 Using SVG icons
    - 3.4 Font Subsetting
4. Design
    - 4.1 Dark Mode Feature
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    - 4.3 Search Bar
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    - 4.6 Page Weight Budget
5. Code
    - 5.1 Lazy Loading
    - 5.2 Agile Methods
    - 5.3 Static Solutions
    - 5.4 Frameworks
    - 5.5 Page Caching
    - 5.6 Compression
    - 5.7 Avoid User Tracking
    - 5.8 Don’t Repeat Yourself
6. Hosting
    - 6.1 Green Hosting
    - 6.2 GZIP Compression
    - 6.3 Block Bad Bots
    - 6.4 Using CDN

1. Images

1.1 Compressing Images

Use the most efficient image format and compression level.

Quick Reference:

- **Photographs:** Use WEBP, or AVIF if you don't need to support Edge.
- **Web Graphics, charts, and illustrations:** Use PNG or SVG formats.
- **Logos:** Use the SVG format.

Try to use the highest compression level that maintains image quality without any significant degradation. For optimizing SVG, refer to 1.2 Optimizing SVG.

Full description:
The most efficient image format should be used based on the content and purpose of each image. Photographs should as a standard use the WEBP format. If you do not need to support Microsoft Edge, you should use the AVIF format which is the current most efficient format for photographs. You should use PNG or SVG formats for web graphics, charts, and illustrations. For logos, you should use the SVG format.

Proper image compression should be done to significantly reduce file size, leading to faster loading times and lower data usage, without obscuring image quality noticeably. Images with a high level of detail or many colors may require lower compression to maintain image quality, while simple images with fewer colors or lower detail can be compressed more aggressively.

Formats that are inefficient or not widely supported, such as BMP or TIFF, should be avoided.

How to implement:
Photographs

1. Use a converter such as https://convertio.co/ and click on "Select Files".
2. Choose the photograph(s) you want to convert from your computer or drag and drop the file into the upload box. You can also select multiple files to convert at once.
3. Once the file(s) are uploaded, select "WEBP" or "AVIF" as the output format.
4. Click the "Convert" button to start the conversion process.
5. Once the conversion is complete, you will be prompted to download the converted file(s).
6. Check the downloaded file(s) to ensure that the quality and compression level are as expected.

Web graphics, charts, and illustrations:

1. Open the software in which your graphic is created (e.g. Adobe Illustrator, Figma, etc.).

2. Select the graphic you want to export as PNG or SVG.
3. Go to the "File" menu and choose "Export" or "Save As".
4. In the export/save dialog box, choose "PNG" or “SVG” as the file format.
5. Choose a location to save the file and give it a name.
6. Click "Export" or "Save" to create the file.

Logos

1. Open the software in which your logo is created (e.g. Adobe Illustrator, Figma, etc.).
2. Select the logo you want to export as an SVG file.
3. Go to the "File" menu and choose "Export" or "Save As".
4. In the export/save dialog box, choose "SVG" as the file format.
5. Select any options for SVG export that you want to use, such as setting the image size, including text as paths, or using CSS styles.
6. Choose a location to save the SVG file and give it a name.
7. Click "Export" or "Save" to create the SVG file.

Why:
By following this guideline, you can ensure that your images are presented in the most efficient and accessible format, improving the sustainability and usability of your webpages.

References:

- https://developer.mozilla.org/en-US/docs/Web/Media/Formats/Image_types
- https://developers.google.com/speed/webp
- https://web.dev/choose-the-right-image-format/
- https://www.sciencedirect.com/topics/computer-science/image-compression
- Greenwood, & He, R. (2021). *Sustainable web design* (Vol. 34, p. 43-48). A book apart.

1.2 Optimizing SVG

All SVG images must be optimized by reducing unnecessary code.

Quick Reference:
Use a tool that optimizes SVGs with the SVGO process, such as SVGOMG.

Full description:
Optimizing SVG files can be achieved by considering various factors such as removing unnecessary elements, reducing the number of anchor points, and simplifying paths. The easiest way to achieve this is by using optimization tools such as SVGO. By doing these optimizations you ensure a faster loading time for your webpage, decrease file size, and improved SEO.

How to implement:

Tools such as SVGOMG or SVGO can be used for the optimization process.

- SVGOMG
- CSS Tricks - Tools for Optimizing SVGs

Why:
By following this guideline, you can ensure that your SVG images are optimized to the smallest file size possible, improving the sustainability and accessibility of your webpages while still maintaining image quality.

References:

- https://imagekit.io/blog/svg-optimization-improves-website-speed/
- https://www.nobledesktop.com/blog/optimizing-svg-files
- Libby, A. (2018). *Beginning SVG: A Practical Introduction to SVG Using Real-world Examples*. Apress.

1.3 Creative use of CSS and SVG

Whenever possible, images and photographs should be replaced with creative CSS or lightweight SVG.

Full description:
Creative use of CSS can create visually engaging designs that are more sustainable than making use of images, while lightweight SVG can be used to create graphics that are smaller in file size than traditional images. When using creative CSS, it's important to ensure that the designs are accessible and don't rely on images for important information or functionality. Similarly, when using SVG, it's important to optimize the file size to the smallest size possible without compromising the image quality 1.2 optimizing SVG.

How to implement:

1. Evaluate the design: Consider if there are any images or photographs that could be replaced with CSS or SVG. Look for opportunities where CSS or SVG can create the same visual effect as the image or photograph.

2. Develop the CSS or SVG: Depending on the design, you may need to create custom CSS or SVG to replace the image or photograph. This can involve creating custom shapes, gradients, or animations with CSS or using vector graphics to create the SVG.

3. Optimize the file size: When using SVG, it's important to optimize the file size to the smallest size possible without compromising the image quality. This can be done by minimizing unnecessary code, removing redundant elements, and reducing the number of points in the vector.

4. Test accessibility: Ensure that the designs created with CSS or SVG are accessible and don't rely on images for important information or functionality. Test the design

with a screen reader or other assistive technologies to ensure that the content is accessible to all users.

5. Monitor performance: After implementing CSS or SVG, monitor the page's performance to ensure that it's not negatively impacted. Keep an eye on the file size and loading times to ensure that the page remains fast and responsive.

Why:
By following this guideline, you can reduce the number of images used on your web pages, improving the sustainability and accessibility of your website while still creating visually engaging designs.

References:

- Libby, A. (2018). *Beginning SVG: A Practical Introduction to SVG Using Real-world Examples*. Apress.
- https://css-tricks.com/books/
- https://css-tricks.com/lodge/svg/

1.4 Responsive Sizing

All rasterized images must be sized responsively using the “srcset”' and “sizes” attributes.

Full description:
The “srcset” and “sizes” attributes should be used to provide images in different sizes and resolutions, which the browser can choose from based on the size of the user's screen. Images should be provided in the smallest resolution possible for each screen size, while still maintaining image quality, to minimize the amount of data downloaded by the user.

How to implement:

1. To use the "srcset" and "sizes" attributes, you'll need to create different versions of the same image in different resolutions or sizes. This can be done manually in an image editing program or through automation using a tool.

2. The "sizes" attribute lets you specify which image size to use at different breakpoints. Determine the breakpoints for different screen sizes (e.g., small, medium, and large) and specify the corresponding image sizes in the "sizes" attribute.

3. In terms of the HTML code, use the "img" tag to specify the image and include the "srcset" and "sizes" attributes. The "srcset" attribute specifies the different image sources, separated by commas, and the "sizes" attribute specifies the image sizes for different screen sizes, separated by commas.

4. When specifying image sizes in the "sizes" attribute, use appropriate units like "vw" or "rem" to make the image size relative to the viewport size or the font size of the page.

5. To minimize the amount of data downloaded by the user, provide images in the smallest resolution possible for each screen size while still maintaining image quality.

6. Test the images at different screen sizes to ensure that the correct image is being displayed and that the image quality is not compromised. You can use browser dev tools to simulate different screen sizes and view the images at different resolutions.

Learn more:

- https://developer.mozilla.org/en-US/docs/Learn/HTML/Multimedia_and_embedding/Responsive_images
- https://web.dev/serve-responsive-images/

Why:
By following this guideline, you can ensure that your images are sized responsively, improving the accessibility and sustainability of your webpages while providing a better user experience for users on different devices and screen sizes.

References:

- Greenwood, & He, R. (2021). *Sustainable web design* (Vol. 34, p. 44-45). A book apart.
- https://imagekit.io/responsive-images/#chapter-4---srcset
- https://css-tricks.com/responsive-images-youre-just-changing-resolutions-use-srcset/

2. Video

2.1 Compressing Videos

Media should be contained inside a format that supports subtitles, and encoded with efficient video- and audio codecs.

Quick Reference:

- Use MP4 as the container.
- Use AV1 as the video codec.
- Use AAC as the audio codec.

Full description:
Some of the most popular container formats are MP4, MKV, AVI, FLV, and MOV. These formats are referred to as containers since they contain video, audio, and subtitle data. You should use the MP4 container which is compatible with the most up-to-date efficient codecs, but keep in mind that the container format alone does not ensure sustainability.

Videos and audio are encoded, and different codecs employ different measures to reduce the size of the files. Generally, newest equals best, although this might not always be the case. By selecting an efficient codec you can reduce the bitrate significantly while still retaining the same perceived quality, thereby greatly reducing the file size.

How to implement:
When rendering your videos, save your video in the **MP4** container format and select the most up-to-date **AV1** codec (*can also be found as **libsvtav1** and **libaom-av1**, choosing either of these is valid*). This setting might be hidden under *Advanced settings* or similar options.

You might also use online converters if they provide any of the above options, but beware as some of these default to *H264* and *H265 (HEVC)*, which are outdated and inefficient codecs.

Why:
By following this guideline, you are able to embed accessible elements into your media files, while efficient codecs allow you to significantly reduce file size.

References:

- https://www.cambridge.org/core/services/aop-cambridge-core/content/view/5972E00494363BE37E3439FAE382DB10/S2048770320000025a.pdf/an-overview-of-coding-tools-in-av1-the-first-video-codec-from-the-alliance-for-open-media.pdf
- https://ieeexplore.ieee.org/abstract/document/8463294
- https://ieeexplore.ieee.org/abstract/document/8456291
- https://www.digdir.no/standarder/aac-advanced-audio-coding/1675
- Den Brinker, A. C., Breebaart, J., Ekstrand, P., Engdegård, J., Henn, F., Kjörling, K., ... & Purnhagen, H. (2009). An overview of the coding standard MPEG-4 audio amendments 1

and 2: HE-AAC, SSC, and HE-AAC v2. *EURASIP Journal on Audio, Speech, and Music Processing*, *2009*, 1-21.

2.2 Auto-Playing

Avoid using auto-play functionality of media, including background videos.

Full description:
Avoid playing video and audio automatically due to its significant consummation of resources, including bandwidth, CPU usage, and battery life on portable devices. Some users may even find auto-playing content distracting or even triggering, particularly if it includes sudden sounds or flashing images. Allowing users to choose whether or not to play content can improve the user experience, along with saving bandwidth if the user is not interested in the video.

How to implement:
For <video> element:

- Make sure that the autoplay attribute is not present.
- For the preload attribute, set it to metadata to make sure the whole video is not downloaded unless needed.
- Learn more about the <video> element: https://developer.mozilla.org/en-US/docs/Web/HTML/Element/video

For YouTube embed (iframe):

- Remove “autoplay” from the allow attribute. If the URL includes “?autoplay=1”, remove it as well.

Why:
By following this guideline, you make sure that video or audio is not bothering the user by being played automatically. Auto-playing media can take up a lot of bandwidth for mobile users, or for those with slower internet connections, which combined with a potential waste of energy being spent makes it a bad design choice.

References:

- https://www.pixeledeggs.com/sustainable-websites-tip-4-get-rid-of-autoplaying-videos/
- https://medium.com/sitesonic/why-you-should-never-use-auto-play-videos-on-your-website-3a8a6babd421

2.3 Animations

Consider using web animations over video whenever possible.

Full description:
Web animation can be an effective way to convey information and engage users. Videos typically require more bandwidth and storage than web animations, and they also present accessibility challenges. Web animations are able to offer accessibility through the use of text alternatives and keyboard controls. These animations can also be more interactive, and customized to suit different devices. The recommended format for short animations is WEBP over GIF, due to its smaller size and accessibility features.

How to implement:

1. There are various animation tools available for creating web animations, such as Adobe Animate, GSAP, or even using CSS animation. Choose the tool that suits your needs and skillset.

2. Optimize the animation for the web by using the appropriate file format and compression. Use a smaller file format such as WEBP over GIF, to reduce file size and improve accessibility features.

3. Consider the user's device and connection speed when creating the animation. Ensure that the animation is optimized for different devices and connection speeds so that users with slower connections or older devices can still have a good experience.

4. Provide alternatives for users who are unable to view the animation. This can include providing a text alternative or a static image. This ensures that the information conveyed in the animation is still accessible to all users.

5. Test the animation: Test the animation on different devices and browsers to ensure that it works correctly and does not affect the website's performance. Test for accessibility by using keyboard controls and screen readers.

Why:
By following this guideline, you can improve accessibility, loading times, and user experience. Web animations are better than videos because they are more accessible, have smaller file sizes, and can be customized for different devices.

References:

- https://www.toptal.com/designers/web/animating-the-web-in-the-post-flash-era
- Greenwood, & He, R. (2021). *Sustainable web design* (Vol. 34, p. 53-55). A book apart.

3. Typography

3.1 System Fonts

Prioritize using built-in system fonts over external fonts.

Quick Reference:
Use as few external web fonts as possible, and use internal fonts.

style.css

```
body {
   /* Option 1 */
   font-family: system-ui;

   /* Option 2 */
   font-family: sans-serif / serif / monospace;
}
```

Full description:
Make use of built-in system fonts to create webpages with faster loading times and lower data usage. Using system fonts can also improve the legibility of text, which is especially important for users with visual impairments.

The fastest font to deliver is the font that is not requested. System fonts and variable fonts are potential ways to reduce requests and bandwidth usage. System fonts are default fonts used by the user interface of the user's device. This means they are preinstalled and do not need to be downloaded.

Exceptions:
Webpages that rely on custom fonts for integral design or branding purposes may not be able to use system fonts exclusively. In such cases, custom fonts should be optimized for the smallest file size possible while still maintaining design and branding integrity (see guideline 3.4 Font Subsetting).

How to implement:
Option 1: Use the "font-family: system-ui" property to use the system fonts of the user's device. For example:

```
body {
  font-family: system-ui, sans-serif;
}
```

3.1 System Fonts

This sets the font of the entire webpage to the system-ui font, which is the default system font on most devices. If the system-ui font is not available, the browser will fallback to a sans-serif font.

Option 2: Use default fonts like "sans-serif" or "serif". For example:

```
h1 {
  font-family: serif;
}
```

This sets the font of all heading elements to a serif font, which is a default font that is available on most devices.

Why:
By following this guideline, you reduce the amount of data used and improve loading times since system fonts are pre-installed on a user's device and therefore don't need to be downloaded.

References:

- https://web.dev/font-best-practices/
- https://www.mightybytes.com/blog/sustainability-web-fonts/

3.2 Font Format

Prioritize using the WOFF2 font format for external fonts.

Full description:
WOFF2 is a highly efficient font format that typically results in smaller file sizes and faster loading times compared to other font formats such as TTF or OTF, and should therefore be prioritized when using external fonts.

How to implement:

- Alternative 1: https://gwfh.mranftl.com/fonts
- Alternative 2: Download WOFF2 directly from Google's Server

Why:
By following this guideline, you can reduce the data usage and loading times. Of the modern font fonts, WOFF2 is the newest, has the widest browser support, and offers the best compression. Because it uses Brotli, WOFF2 compresses 30% better than WOFF, leading to less data to download and therefore faster performance.

References:

- https://web.dev/font-best-practices/
- https://www.aleksandrhovhannisyan.com/blog/downloading-and-optimizing-google-fonts/#:~:text=Head%20over%20to%20https%3A%2F%2F,copy%2Dpaste%20into%20your%20CSS

3.3 Using SVG icons

Prioritize using SVG icons over icon fonts.

Full description:
Utilize SVG icons instead of icon fonts, to reduce data usage and increase customization options. Unlike icon fonts that necessitate downloading a complete font file, SVG icons can be inserted directly into the webpage's code. This results in faster loading times and fewer server requests. Moreover, with CSS modifications, SVG icons are more adaptable to design changes.

How to implement:
Export your own icons as SVG, or use free icon libraries such as https://icons.getbootstrap.com to download SVG icons.

Then, insert the SVG code directly into the webpage's code. For example, to insert a Bootstrap icon, copy the SVG code from the Bootstrap website and paste it into the HTML code. Then, use CSS to modify the icon's color, size, and other properties.

Why:
SVG icons are more efficient than icon fonts. They reduce data usage and loading times, and increase customization options.

References:

- https://www.lambdatest.com/blog/its-2019-lets-end-the-debate-on-icon-fonts-vs-svg-icons/
- https://cloudfour.com/thinks/seriously-dont-use-icon-fonts/

3.4 Font Subsetting

Do font-subsetting for external fonts to create a custom font which only includes the characters needed.

Full description:

When using external fonts, subset them to create a custom font which only includes the characters needed for your web page rather than including the whole font set. This will optimize the file size and reduce bandwidth usage by removing unnecessary glyphs and characters.

How to implement:

1. Use a tool such as https://www.fontsquirrel.com/tools/webfont-generator.

2. Click on the "Add Fonts" button and upload the font file that you want to subset. Font Squirrel supports various font formats, such as TTF, OTF, WOFF, and WOFF2.

3. Font Squirrel offers various subsetting options, such as selecting which characters to include, selecting font styles and weights, and adjusting the font optimization settings. Choose the options that suit your needs.

4. After you have selected the subsetting options, click on the "Download Your Kit" button to download the subsetted font files. Font Squirrel generates the subsetted font files in various formats, such as WOFF, WOFF2, EOT, and SVG.

5. Once you have downloaded the subsetted font files, implement them on your web page by adding the relevant CSS code. Font Squirrel provides a CSS template that you can use as a starting point.

- Glyphhanger Node package:

```
npm install -g glyphhanger
glyphhanger --subset=*.ttf --LATIN --formats=woff2
```

Why:

Subsetting fonts reduces the file size and bandwidth usage of your web page. This is especially useful for web pages that use external fonts, as the font files are usually large in size. Subsetting fonts can also improve the performance of your web page by reducing the number of glyphs that need to be rendered.

References:

- https://www.fontsquirrel.com/tools/webfont-generator
- https://web.dev/font-best-practices/
- https://github.com/zachleat/glyphhanger#installation
- https://www.npmjs.com/package/glyphhanger

4. Design

4.1 Dark Mode Feature

Offer a dark mode feature to reduce energy consumption on OLED screens.

Full description:
Dark mode is a feature that allows users to switch a website's color scheme to a darker version. This feature can reduce eye strain and improve visibility in low-light environments. Additionally, it can also help reduce energy consumption on devices with OLED screens, as darker colors use less energy compared to brighter ones.

For the implementation of this feature, it is important to ensure that it is accessible and easy to use for all users. Provide clear instructions on how to activate or deactivate the feature, and ensure that it does not interfere with any other accessibility concerns.

How to implement:

- Ensure that the dark mode feature is accessible and easy to use for all users. Provide clear instructions on how to activate or deactivate the feature, and ensure that it does not interfere with any other accessibility concerns. Following this https://css-tricks.com/a-complete-guide-to-dark-mode-on-the-web/ guide can help you implement this feature.
- A simple way to implement dark mode is to use the prefers-color-scheme media query. This media query allows you to specify different styles for light and dark color schemes. For example, you can use the following CSS to specify a dark background color for the body element when the user's system is set to dark mode:

```
@media (prefers-color-scheme: dark) {
  body {
    background-color: #333;
  }
}
```

- If you are using a CSS framework, you can use the built-in dark mode feature. For example, https://tailwindcss.com/docs/dark-mode provides a dark mode feature that can be enabled by adding the dark class to the root element.
- If you are using a CSS-in-JS library, you can use the built-in dark mode feature. For example, https://emotion.sh/docs/dark-mode provides a dark mode feature that can be enabled by adding the dark class to the root element.
- Another simple way to implement dark mode is to follow this guide: How to Implement a Dark Mode with CSS and 3 Simple Lines of Javascript. This guide uses a CSS variable to store the current color scheme, and a JavaScript function to toggle the color scheme between light and dark.

Why:

By following this guideline, you can help save energy consumption on end-user devices. Darker colors use less energy on OLED screens, which means that devices with these types of screens will consume less power when displaying a website that uses darker colors. This can lead to longer battery life on mobile devices, reduced energy costs for users, and a lower carbon footprint overall. Dark mode also raises accessibility concerns by reducing eye strain and improving visibility in low-light environments.

References:

- https://www.linkedin.com/pulse/dark-mode-greener-suyash-mahajan?trk=articles_directory
- https://css-tricks.com/a-complete-guide-to-dark-mode-on-the-web/
- https://emotion.sh/docs/dark-mode
- https://dev.to/daveyhert/how-to-implement-a-dark-mode-with-css-and-3-simple-lines-of-javascript-576
- https://www.wholegraindigital.com/blog/dark-colour-web-design/

4.2 User Journey

Design the user journey of the website to be as intuitive and efficient as possible.

Full description:
Designing websites with the user journey in mind is critical for providing an intuitive and efficient user experience. It is recommended to conduct user research and user testing to gain insights into user behavior and preferences. This can help identify common user goals and tasks, and inform the design of a website's navigation and content hierarchy.

When designing a website, it is also important to ensure that the content and layout are organized in a logical and user-friendly way. This means using clear headings and labels, avoiding cluttered layouts, and providing easy-to-use navigation and search functions.

How to implement:

- Conduct user research and user testing to gain insights into user behavior and preferences.
- Design a website's navigation and content hierarchy based on user goals and tasks.
- Ensure that the content and layout of a website are organized in a logical and user-friendly way.
- Use clear headings and labels.
- Avoid cluttered layouts.
- Provide easy-to-use navigation and search functions.

Learn more here:

- https://xd.adobe.com/ideas/process/user-research/user-journey-vs-user-flow/
- https://webflow.com/blog/user-journey

Why:
By following this guideline, users are more likely to find what they need quickly and easily, which will reduce the time they spend browsing and consuming resources. This will minimize the overall energy consumption of the website. Considering the user journey will also improve the accessibility and usability of your solution.

References:

- https://greentheweb.com/environment-centered-user-journey-maps-incl-example-and-template/#lanesf%C3%BCrnachhaltigkeit

4.3 Search Bar

For websites consisting of more than five pages, provide a search bar that can be used to find content efficiently.

Full description:
Provide a search bar on websites with more than five pages to greatly improve the user experience by making it easier for users to find what they need in an efficient manner. A search field allows users to search for specific content or information, reducing the time and resources required to navigate through a website's pages and menus.

How to implement:

- Make the search bar visible and prominent on all platforms.
- Put the search where people expect it to be, on all pages.
- Make the search input large enough to enter text and work as a touch target.
- Give the search input a label and a magnifying glass icon to indicate its purpose.
- Don't force users to click the search icon to display the text input.
- Provide suggestions and completions.
- Enable synonym search or other methods of dealing with ambiguous queries.
- Be "type tolerant" and allow users to search for content using different words.
- Retain query text.
- Test the search bar with users.

Here are some examples of responsive search bars:

- Responsive search input using JavaScript
- Responsive search input: using a form

Why:
By following this guideline, users are more likely to find what they need quickly and easily, which will reduce the time they spend browsing and consuming resources. This will minimize the overall energy consumption of the website. Allowing the user to find what they need more easily will also improve the accessibility and usability of your solution.

References:

- https://www.w3.org/WAI/tutorials/forms/labels/#search-bar
- https://www.greenmellenmedia.com/why-your-website-needs-a-search-function/

4.4 Content With Purpose

Focus on minimalism, by only including content that has a clear purpose for your design.

Full description:
Design your web pages to have content with a clear purpose for users so they can find the information they need quickly and efficiently. To achieve this, it is important to adopt a minimalist approach to content creation, focusing on creating content that is concise, clear, and easy to understand. This means avoiding unnecessary or redundant information, using simple and straightforward language, and using headings and formatting to guide users through the content. In addition, you must evaluate each piece of content (especially images and videos) carefully to determine if it is necessary and relevant to the user experience.

How to implement:

1. Before creating any content, identify the main purpose of your webpage. Ask yourself what users should be able to achieve or learn from your webpage. This will help you create a clear focus for your content.

2. Prioritize your content by identifying the most important information that users need to achieve their goals on your webpage. Ensure that this information is easily accessible and prominently displayed.

3. Identify any content that does not support the main purpose of your webpage or that is redundant. Remove this content to ensure that users are not distracted or overwhelmed by unnecessary information.

4. Use simple and straightforward language to communicate your message. Avoid using technical jargon or complex language that might confuse users.

5. Use headings and formatting to organize your content and guide users through the information on your webpage. Headings should be descriptive and provide a clear overview of the content that follows.

6. Evaluate each image and video carefully to ensure that it is necessary and relevant to the user experience. Consider the purpose of the media and whether it adds value to the user experience. Remove any images or videos that are not necessary or relevant.

7. Test your content with users to ensure that it is effective in achieving the main purpose of your webpage. Ask for feedback on the clarity and relevance of your content, and make any necessary changes based on user feedback.

Why:
By following this guideline, you will ensure that all content on your website serves a clear and necessary purpose. Especially when ensuring that all video and images on a website serve a clear and necessary purpose, you can reduce a lot of data. Combined, this focus on minimalism will lead to improved accessibility and usability of your web pages, and will reduce the loading time due to less data transfer.

References:
- https://enlear.academy/sustainable-web-design-everything-you-need-to-know-64260461a0d6
- https://www.w3.org/WAI/tutorials/page-structure/content/

4.5 Mobile-First Principle

Design your website using the mobile-first principal.

Full description:
Mobile devices have limited screen space, slower internet connections, and may be used in various contexts, such as while on the go. Prioritize the mobile experience, to create a website or application that is optimized for speed and ease of use. This should translate to better performance for your responsive designs when you optimize for larger screens.

How to implement:
1. Begin your web page design process by designing for mobiles. This will help you prioritize content and features that are most important for users on the go.

2. Use responsive design How to implement to ensure your website or application adapts to different screen sizes and devices. This includes using flexible grids and images, as well as media queries to adjust layout and styling based on screen size.

3. Mobile devices have limited screen space, so it's important to simplify navigation to make it easy for users to find what they're looking for. Consider using a hamburger menu or other mobile-friendly navigation options.

4. Mobile devices may have slower internet connections, so it's important to optimize your website or application for fast page load times. This includes minimizing the use of large images, using lazy loading to load images and content as the user scrolls, and minimizing HTTP requests.

5. Mobile devices rely on touch-based interaction, so it's important to design with touch-friendly elements in mind. This includes using large buttons and links that are easy to tap and ensuring that touch-based interactions are responsive and intuitive.

Why:
By following this guideline, you prioritize the needs of users who access your solution from a mobile device. Overall, your website will be better optimized for speed and require less bandwidth. This can lead to increased engagement and reduced bounce rates.

References:

- https://www.mightybytes.com/blog/mobile-first-sustainability/
- https://www.smashingmagazine.com/2011/01/guidelines-for-responsive-web-design/
- https://web.dev/learn/design/

4.6 Page Weight Budget

Set a maximum page weight limit for your web pages.

Full description:
Page weight refers to the total size of all the files that make up a web page, including images, videos, scripts, stylesheets, and other assets. The larger the page weight, the longer it takes to load, which can lead to a poor user experience and increased energy consumption. A good starting point is to aim for a budget of 1-2 MB per page, but this will vary depending on the needs of your website.

How to implement:
How to set a page weight budget, by Wholegrain Digital

1. Benchmark the old version of the same website and also the main competitors to identify what is typical in the industry. Aim to be at least 20% more efficient than the best in the business.
2. Identify the worst likely connection of your target users and their expectation of load times. Calculate the budget from that. A tool such as http://www.performancebudget.io/ can be used to estimate this.
3. se your experience and gut instinct to agree a budget from these two numbers. It might be a range, with point 1 being the minimum standard and point 2 being the stretch goal.

The above process is not inherently complicated and anyone in the team could follow these steps and propose a budget. What's more important is that somebody takes ownership of the budget from start to finish, and seeing as the Project Manager is

accountable for the overall success of the project including its financial budget, it makes sense that they take the lead on the page weight budget too.

They need to take into account the practical needs of the client, the websites target users and any known technical constraints that are defined in the project brief. For example, if you know that the website must have Intercom live chat integrated, then you should set the budget to allow for that.

Source: https://www.wholegraindigital.com/blog/how-to-page-weight-budget/

Why:
By following this guideline, you will focus on reducing the overall file sizes of your web pages. This will lead to reduced loading times for the user, and less files to transfer which reduces energy consumption.

References:

- https://www.mightybytes.com/blog/performance-budget/
- https://www.performancebudget.io/

5. Code

5.1 Lazy Loading
Use lazy loading to defer the loading of non-critical media until they are needed.
Full description: Apply lazy loading to images and other media which are non-critical to the user experience and can be loaded later. This might include images below the fold, or media that only appears after user interaction, such as a click or scroll. **Important:** Only use lazy-loading for dynamic websites, and not for static solutions. For static solutions, refer to 6.4 Using CDN.
How to implement: 1. Identify the images and other media on your website that are non-critical and can be loaded later. This might include images below the fold, or media that only appears after user interaction, such as a click or scroll. 2. To enable lazy loading, add the "loading" attribute to the image or media tag. This attribute tells the browser to defer the loading of the media until it's needed. Here is an example: <img src="example.jpg" loading="lazy" alt="Example Image"> 3. Test your lazy loading implementation and adjust as necessary to ensure that it works properly and doesn't negatively impact the user experience. Learn more here: https://developer.mozilla.org/en-US/docs/Web/Performance/Lazy_loading
Why: By following this guideline, you can reduce the data transfer leading to a better experience and reduced energy consumption.
References: ● https://developer.mozilla.org/en-US/docs/Web/Performance/Lazy_loading ● https://www.towards-sustainability.com/tag/lazy-loading/ ● https://web.dev/lazy-loading-images/ ● https://web.dev/lazy-loading-video/ ● https://web.dev/lazy-loading/ ● https://www.towards-sustainability.com/tag/lazy-loading/

5.2 Agile Methods

Use Agile methods to promote sustainable web design through efficient project management and continuous improvement.

Full description:
Make use of Agile methods to prioritize collaboration between team members, including designers, developers, and stakeholders. Regular meetings, such as daily stand-ups and sprint reviews, can help to ensure that everyone is working towards the same goals and that any issues are identified and resolved quickly.

By adopting Agile methods, you can help to improve the sustainability of web design by promoting more efficient and effective work practices, reducing waste, and improving overall project outcomes. The combination of Agile and sustainable web design practices are also a good way to save money due to more efficient server usage and quicker project outcomes.

How to implement:
Follow the Agile Manifesto to promote collaboration and continuous improvement. Here is some great resources for learning more about Agile methods:

- https://www.agilealliance.org/agile101/
- https://www.atlassian.com/agile

Why:
By following this guideline, your projects can promote collaboration, efficiency, and continuous improvement. This will lead to improved project outcomes, reduced environmental impact, and increased user satisfaction.

References:
- https://www.in-imago.com/en/inimagobooks/agility-principle/principle-8-agile-processes-promote-sustainable-development-the-team-maintains-a-constant-pace-indefinitely/
- https://agilemanifesto.org/
- https://www.agilealliance.org/
- https://www.agilealliance.org/agile101/
- https://www.atlassian.com/agile

5.3 Static Solutions

Go static for your website whenever possible, including minimizing the use of JavaScript.

Full description:

Go for static website solutions whenever you do not have the need for a dynamic solution. Static solutions make use of static files, such as HTML, CSS, and JavaScript, to build the website.

For each line of JavaScript you wish to include, evaluate whether it is necessary and appropriate. For example, consider whether the functionality is only possible to achieve by using JavaScript or whether it can be achieved through other means, such as using CSS animations.

How to implement:

1. Consider whether a static solution is appropriate for your website. If your website requires dynamic content, such as user-generated content or real-time updates, then a dynamic solution may be necessary. However, if your website primarily displays static content, such as blog posts or product pages, then a static solution may be a better fit.
2. If a static solution is appropriate, use static files, such as HTML, CSS, and JavaScript, to build your website. This means that each page of your website is a separate HTML file, which can be loaded quickly and easily.
3. For each line of JavaScript you wish to include, evaluate whether it is necessary and appropriate. Consider whether the functionality is only possible to achieve by using JavaScript or whether it can be achieved through other means, such as using CSS. (Refer to 1.3 Creative Use Of CSS And SVG)

Why:
By following this guideline, your webpage can be loaded quickly and efficiently, leading to improved website performance and reduced energy consumption.

References:

- https://miikavonbell.com/articles/sustainable-web-design-principles/
- https://www.staticgen.com/

5.4 Frameworks

Consider whether the use of a framework is needed or not, and use them wisely.

Full description:
Frameworks are pre-built libraries of code that can help developers create websites more quickly and efficiently. While frameworks can save time and effort, they can also have a significant impact on website performance and sustainability.

Before using a framework such as React, evaluate whether it is necessary and appropriate. Consider factors such as the size and complexity of the website, the level of functionality required, and the skills and experience of the development team. In some cases, a framework may not be necessary or may even be counterproductive.

How to implement:

1. Consider the size and complexity of the website, as well as the level of functionality required. If the website is relatively simple and doesn't require a lot of functionality, a framework may not be necessary.

2. Consider the skills and experience of the development team. If the team is experienced with a particular framework and has used it successfully on previous projects, using the same framework may save time and effort.

3. Consider the impact that using a framework may have on website performance. Frameworks can be heavy and may slow down the website's loading time, which can negatively impact the user experience.

4. Before using a framework, consider whether there are any alternatives that may be more appropriate. For example, there may be simpler, lightweight libraries that can achieve the same functionality without the added weight of a full framework.

5. If a framework is deemed necessary, use it wisely. Avoid using unnecessary features and keep the framework updated to avoid security vulnerabilities and performance issues.

Why:
By following this guideline, you can reduce the use of unnecessary code which will lead to faster load times and less energy consumption. It also removes the need of spending resources on learning a more advanced framework.

References:

- Greenwood, & He, R. (2021). *Sustainable web design* (Vol. 34, p. 63). A book apart.

5.5 Page Caching

Make use of caching to minimize server requests.

Full description:
Website caching is the process of storing frequently accessed website data in a user's device or a server's memory to reduce server requests and improve page loading speed. Cache the static content of the website, such as images, HTML, CSS, and JavaScript files.

How to implement:

1. Identify the static content of the website, such as images, HTML, CSS, and JavaScript files. These files are less likely to change frequently and can be cached without causing issues.

2. To enable caching on the server, you'll need to add some code to your server configuration file. The exact code will depend on the server software you're using. Here are some examples:

Apache: To enable caching on Apache, add the following code to your .htaccess file:

```
# Enable caching
ExpiresActive On

# Cache files for 1 month
ExpiresDefault "access plus 1 month"
```

Nginx: To enable caching on Nginx, add the following code to your server block:

```
# Enable caching
location ~* \.(jpg|jpeg|png|gif|ico|svg|woff|woff2|ttf)$ {
  expires 1M;
  add_header Cache-Control "public, no-transform";
}
```

3. Set expiration times for cached content to ensure that users see the latest version of the website when changes are made. This will also help prevent users from seeing outdated content. For example, you can set the expiration time to 1 month, as shown in the examples above.

4. Use version control to ensure that changes to the website's static content are tracked and new versions are created. This will help ensure that users are seeing the latest version of the website.

Why:
By following this guideline, you can significantly reduce the website's energy usage required to generate and deliver web pages.

References:

- https://sustainablewebdesign.org/is-server-side-caching-or-static-technology-in-place-to-minimize-server-load/
- https://innocode.com/blog/web-sustainability-in-our-development/

5.6 Compression

Minimize the size of code files by compressing them.

Full description:
Compressing code files reduces the size of the files and therefore reduces the time it takes to download them. This is especially important for mobile devices, which have

limited bandwidth and processing power. Compressing code files also reduces the amount of data that needs to be stored on the server, which can reduce the cost of hosting the site. Remove unnecessary characters, whitespace, and comments to compress HTML, CSS, and JavaScript files.

Minification is the process of minimizing code and markup in your web pages and script files. It's one of the main methods used to reduce load times and bandwidth usage on websites. Minification dramatically improves site speed and accessibility, directly translating into a better user experience. It's also beneficial to users accessing your website through a limited data plan and who would like to save on their bandwidth usage while surfing the web. Source: https://www.imperva.com/learn/performance/minification/

How to implement:
HTML Compression
Use a tool like HTMLMinifier, which removes unnecessary whitespace, comments, and attributes, making your HTML files smaller in size.

CSS Compression
Use a tool like CSSNano, which removes unnecessary whitespace, comments, and properties, making your CSS files smaller in size.

JavaScript Compression
Use a tool like Google's Closure Compiler, which removes unnecessary whitespace, comments, and variables, making your JavaScript files smaller in size.

Image Compression
Refer to 1.1 Compressing Images to learn more about compressing images.

SVG Compression
Refer to 1.2 Optimizing SVG to learn more about compressing SVGs.

Video Compression
Refer to 2.1 Compressing Videos to learn more about compressing videos.

Why:
By following this guideline, you ensure that your files are compressed and optimized for delivery. This can reduce the size of the server requests and improve the overall website performance.

When creating HTML, CSS and JavaScript (JS) files, developers tend to use spacing, comments and well-named variables to make code and markup readable for themselves. It also helps others who might later work on the assets. While this is a plus in the development phase, it becomes a negative when it comes to serving your pages. Web servers and browsers can parse file content without comments and well-structured code, both of which create additional network traffic without providing any functional benefit.

Source: https://www.imperva.com/learn/performance/minification/
References: ● https://www.imperva.com/learn/performance/minification/

5.7 Avoid User Tracking
Use tracking scripts only for justified reasons and with explicit user consent.
Full description: Tracking scripts can be used to collect information about users' browsing behavior and online activities, which can be used for advertising, analytics, and other purposes. You should use user tracking scripts only for justified reasons and with explicit user consent.
How to implement: 1. Determine the purpose of the tracking script and ensure that it is necessary for the website's functionality or business goals. Examples of justified reasons include analytics for improving the user experience or security purposes. 2. Obtain explicit user consent before implementing any tracking script on your website. Users must be informed about the purpose of the script and how their data will be collected, processed, and used. Ensure that the user has a clear and easy way to opt-in or opt-out of tracking. 3. Limit the tracking to what is necessary for the website's functionality or business goals. Avoid collecting sensitive data such as personally identifiable information, health data, or financial data. 4. Respect users' preferences, and allow them to withdraw their consent and delete their data if they wish. Provide an easy way for users to opt-out of tracking and delete their data, and ensure that their preferences are respected across all devices and platforms.
Why: By following this guideline, you will ensure not to be tracking your users unless it is really needed. This will lead to a more privacy-concerning solution, along with reduced data transfer and load on the user’s device.
References: ● https://sustainablewebdesign.org/does-the-website-avoid-tracking-user-behaviour-and-collecting-data-unnecessarily/

5.8 Don’t Repeat Yourself
Use the DRY (Don’t repeat yourself) principle to reduce code duplication and improve code maintainability.
Full description: The DRY (don't repeat yourself) principle is a best practice in software development that recommends software engineers to do something once, and only once. The concept, which is often credited to Andrew Hunt and David Thomas, authors of "The Pragmatic Programmer," is the tongue-in-cheek opposite of the WET principle, which stands for "write everything twice." According to the DRY principle, every discrete chunk of knowledge should have one, unambiguous, authoritative representation within a system. The goal of the DRY principle is to lower technical debt by eliminating redundancies in process and logic whenever possible. Source: https://www.techtarget.com/whatis/definition/DRY-principle
How to implement: Redundancies in process To prevent redundancies in processes (actions required to achieve a result), followers of the DRY principle seek to ensure that there is only one way to complete a particular process. Automating the steps wherever possible also reduces redundancy, as well as the number of actions required to complete a task. Redundancies in logic To prevent redundancies in logic (code), followers of the DRY principle use abstraction to minimize repetition. Abstraction is the process of removing characteristics until only the most essential characteristics remain. An important goal of the DRY principle is to improve the maintainability of code during all phases of its lifecycle. When the DRY principle is followed, for example, a software developer should be able to change code in one place, and have the change automatically applied to every instance of the code in question. Source: https://www.techtarget.com/whatis/definition/DRY-principle
Why: By following this guideline, you make your code easier to maintain, your development process will be efficient and you avoid the unnecessary transfer of duplicated code.
References: ● https://www.ionos.com/digitalguide/websites/web-development/clean-code-principles-advantages-and-examples/ ● https://www.techtarget.com/whatis/definition/DRY-principle

6. Hosting

6.1 Green Hosting
Choose web hosting services that use renewable energy resources (green hosting) and which are located close to the majority of your users.
Full description: Web hosting services that prioritize sustainability typically use renewable energy References, such as wind or solar power, to power their data centers. This reduces the carbon footprint associated with electricity generation and can significantly decrease the environmental impact of website hosting. In addition to considering green hosting, the location of the server should be as close to your majority of users as possible.
How to implement: To find a green hosting provider, check the following page for a list of providers that use renewable energy to power their data centers: https://www.greengeeks.com/green-web-hosting/
Why: By following this guideline, you ensure that your hosting is running on renewable energy and not causing such an environmental impact as traditional hosting. You will also increase the loading speed for your users by ensuring that the server is located closer to your users.
References: ● https://www.wholegraindigital.com/blog/choose-a-green-web-host/ ● https://www.greengeeks.com/green-web-hosting/

6.2 GZIP Compression
Use GZIP compression for HTTP requests fetching HTML, CSS, and JavaScript files.
Full description: Use GZIP compression to reduce the size of website files, such as HTML, CSS, and JavaScript files, by compressing them before they are sent to the user's browser. This can help to improve website performance by reducing the amount of data that needs to be transmitted, resulting in faster loading times and lower bandwidth usage.
How to implement: Follow the steps below to enable GZIP compression for your website on this website: https://blog.hubspot.com/website/gzip-compression
Why:

By following this guideline, you can significantly reduce the size of website files, often by 70% or more, resulting in faster loading times and improved website performance. This can lead to a better user experience and reduced energy consumption. GZIP compression can help to improve website performance by reducing the amount of data that needs to be transmitted, resulting in faster loading times and lower bandwidth usage.

References:

- https://sustainablewww.org/principles/how-to-configure-gzip-compression-to-speed-up-your-website-with-nginx
- https://blog.hubspot.com/website/gzip-compression

6.3 Block Bad Bots

Block bad bots to improve website security and reduce server load.

Full description:
Bad bots are automated programs that can visit websites and perform malicious activities, such as scraping content, spamming, or launching attacks. These bots can cause various issues for website owners, including security breaches, data theft, and server overload, which can result in website downtime or slow loading times. Implement measures to block bad bots from accessing the website.

How to implement:

1. Create a robots.txt file to indicate which bots are allowed to access your website and which are not. This file tells good bots which pages to crawl and which ones to avoid. Bad bots may ignore this file, but it's still a good first line of defense.

2. Use a CAPTCHA to block bots from automated form submissions. This will help prevent spammers from using your website to send spam emails or comments.

3. Set up a firewall to block known bad bot IP addresses. A firewall can be configured to block traffic from specific IP addresses, countries, or regions. This can help prevent malicious bots from accessing your website.

4. Regularly monitor your website traffic to detect unusual activity. This can help you identify bots that are trying to access your website and take action to block them.

5. Use a web application firewall (WAF) to help detect and block malicious bots in real time. It uses a set of rules to filter incoming traffic and block requests from known bad bots.

6. Use a blacklist to block traffic from known bad bot user agents. This can be done using your website's .htaccess file. User agents are part of a bot's HTTP header and can be used to identify bad bots.

7. Rate limiting can help prevent bots from overwhelming your website by limiting the number of requests a bot can make in a given time period. This can help prevent DDoS attacks.

8. Keep your website's software up to date to ensure that any security vulnerabilities are patched. This can help prevent bots from exploiting vulnerabilities to gain access to your website.

Why:
By following this guideline, you can improve website security, reduce server load, and ensure a better user experience for your visitors. More than 40% of Internet traffic is generated by bots, with a notable fraction of them being bad bots, which increases the need for measurements.

References:

- https://sustainablewww.org/principles/block-unwanted-and-spammy-bots-with-robotstxt-and-speed-up-your-website
- https://sustainablewebdesign.org/is-bad-bot-traffic-blocked-from-the-site/

6.4 Using CDN

Use CDN (Content Delivery Network) if your website is used across widespread areas.

Full description:
Use CDNs to cache your website content on servers located in multiple geographic locations. Then, when a user requests a web page, the CDN delivers the content from the server that is closest to them, reducing the distance that the data must travel and improving website performance.

How to implement:
Follow this website to learn more about CDN:
https://www.hostinger.com/tutorials/improving-website-performance-using-a-cdn

Why:
By following this guideline, you can avoid using hosting servers in multiple locations which would consume extra energy. Additionally, you also improve the website performance for the users.

References:

- https://sustainablewebdesign.org/is-the-hosting-located-as-close-as-possible-to-the-core-user-base-or-use-a-cdn/
- https://sustainablewww.org/principles/when-to-serve-your-website-through-a-cdn-and-when-not-to

E Sustainable Practices

This appendix includes the sustainable practices that were included in the Sustainable Web Design Guidelines draft, as mentioned in Study 3: Guidelines.

Sustainable Practices for Images

Practice	Source
Use WebP (or Avif) for photographs	Greenwood, p.43
Use PNG for simple images that only use a few block colours	Greenwood, p.43
Converting 24-bit PNG files to PNG-8	Greenwood, p.44
Use responsive image sizing (**srcset** and **sizes** attributes)	Greenwood, p.44-45
Applying a slight blur to photographs	Greenwood, p.46
Being creative with CSS (replacing images/photographs)	Greenwood, p.46
Using lightweight SVG whenever possible to replaces images	Greenwood, p.46
Optimizing SVG vector files	Greenwood, p.48
Use image compression tools	Greenwood, p. 44
Consider the size/dimensions of the image	Greenwood, p. 44
Making the image monochrome	Greenwood, p. 51

Sustainable Practices for Videos

Practice	Source
Use MP4 container	Greenwood, p.44
Use AV1 codec	Hulleberg, p.xx
Avoid auto playing video	Greenwood, p. 54
Consider using web animation	Greenwood, p. 54
Consider the length of the video (every second matters)	Greenwood, p. 55
Use WEBP over GIF for short animations	Greenwood, p. 56

Sustainable Practices for Fonts

Practice	Source
Use system fonts	Greenwood, p. ; Frick, s.171
Use font-subsetting	Greenwood, p.
Keep it to two fonts maximum	Frick, s.172
Use SVG for icons, not icon fonts	Frick, s.172
Consider typefaces designed for screen, rather than print	Frick, s.172
Consider using mostly system fonts	Frick, s.173
Use more efficient format WOFF2	Greenwood, p. 64

Sustainable Practices for SEO

Practice	Source
Add clear meta description containing keywords, no longer than 155 character	Frick, s.142
Title tag, 55 characters or less using your page's primary keyword	Frick, s.143
header tags, great for keywords	Frick, s.143
Include the keyphrase in the page's url	Frick, s.143
add keywords and phrases in the body of the content.	Frick, s.143
Alt tags with descriptive keywords in images	Frick, s.143
Advice: "don't put something out there unless it matters"	Frick, s.146

Sustainable Practices for Design

Practice	Source
Use Mobile-first principle	Frick, s.184
Use Progressive Enhancement	Frick, s.185
Use Responsive Design in tandem with Mobile-First and Progressive Enhance	Frick, s.186
Reduce unnecessary page loads / avoid long user journeys	Greenwood, p. 37
Be mindful with motion	Greenwood, p. 53
Consider wheter an image carousel is needed or not	Greenwood, p. 56-57
Provide a search field	Web Sustainability Pocket Guide
Consider the user journey	Web Sustainability Pocket Guide
Enable GZIP compression for all HTTP requests	Web Sustainability Pocket Guide
Use lazy loading	Frick
In general, minimalism (content with actual purpose)	Greenwood
Setting page weight budget	sustainablewebdesign.org

Sustainable Practices for Workflows

Practice	Source
Agile UX practices is completely predicated on the idea of reducing waste	Frick, s.157
Use Lean personas	Frick, s.158
Use Lean Wireframing	Frick, s.160
Patterns	Frick, s.162-165
If you have the choise, use Vanilla JavaScript over TypeScript and PHP	Greenwood, p. 62
Avoid using JavaScript for animating elements, use CSS instead	Greenwood, p. 63
Go static if possible. Is it really needed to use JavaScript, or front-end framewo	Greenwood, p. 63
Avoid tracking scripts. Discuss if it is really needed, and what to learn from coll	Greenwood, p. 64
Page caching	Greenwood, p. 67
Compress your code	Greenwood, p. 70
Block the bad bots	Greenwood, p. 71
Use green web hosting	Greenwood, p. 73
Use CDN	Greenwood, p. 80

Sustainable Practices for Colours

Practice	Source
Darker colours lead to less energy spent	Greenwood, p.49

F User Feedback Survey

This appendix includes the questions asked in the user testing of our guidelines as explained in Testing the Guideline for Clarity and Relevance.

SWDG Feedback

About the survey
This survey is part of research conducted by third-year web development students at NTNU in Gjøvik.

The aim of the survey is to gather feedback on guidelines for implementing sustainable web design, developed as part of the bachelor thesis "Sustainable Web Design Guidelines" by Henrik Landgraff Granum, Magnus Moen, Ola Hulleberg and Sivert Gullberg Hansen.

No personal data is collected and the answers are anonymous. Please note that your access to the website (sustainableweb.net) is personal, and the website and its data must not be shared with others. Thank you for participating!

If you already have spent some time with the guidelines (https://sustainableweb.net/guidelines) you can proceed to the next questions.

Part 1: Demographics

Which age group do you belong to?

- 18 - 24
- 25 - 34
- 35 - 44
- 45 - 54
- 55 - 64
- 65+

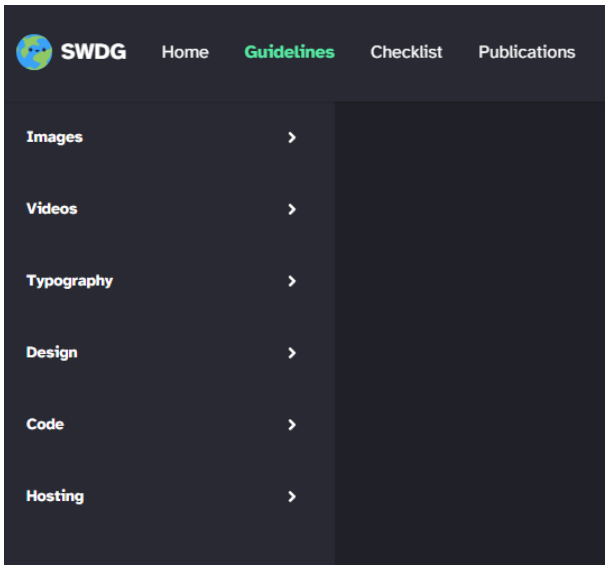
What is your gender?

- Male
- Female

What is your current role?

- Student of Interaction Design
- Student of Web Development
- Designer
- Developer
- Academia

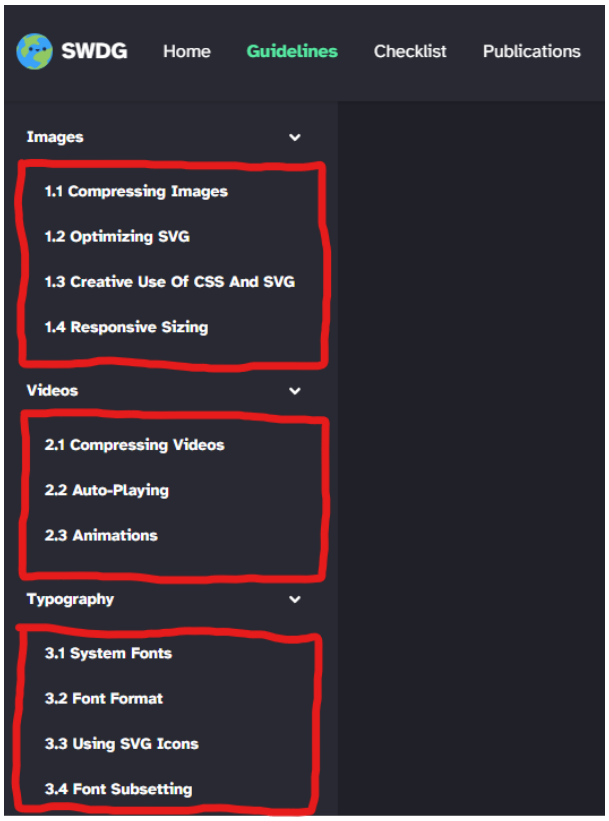
Part 2: Guideline



To what degree did the sections (Images, videos etc.) make sense to you?

- To no degree
- To some degree
- Neutral
- To a big degree
- To a large degree

Do you have any feedback for the sections? Any section you are missing or wish to be different?



To what degree are the guideline titles self-explanatory regarding its content?

- To no degree
- To some degree
- Neutral
- To a big degree
- To a large degree

Do you have any feedback for the guideline titles? Are any of them confusing to you?

Is there any sustainable web design guidelines you are missing or feel that should not be included? Please explain.

How understandable and readable was the guidelines overall?

- To no degree
- To some degree
- Neutral
- To a big degree
- To a large degree

Was there any guideline(s) that was unclear or less understandable? Please explain.

Compared to existing web accessibility guidelines (WCAG), how is your overall experience of our guideline?

Very dissatisfied
Somewhat dissatisfied
Neutral
Somewhat satisfied
Very satisfied

How useful did you find the guideline sections?

Quick Reference

Not at all useful
Slightly useful
Moderately useful
Very useful
Extremely useful

Description

Not at all useful
Slightly useful
Moderately useful
Very useful
Extremely useful

How to implement

Not at all useful
Slightly useful
Moderately useful
Very useful
Extremely useful

Why?

Not at all useful
Slightly useful
Moderately useful
Very useful
Extremely useful

References

Not at all useful
Slightly useful
Moderately useful
Very useful
Extremely useful

Do you have any feedback for the guideline sections?

How likely is it that you would you use the guidelines in a future project?

To no degree
To some degree
Neutral
To a big degree
To a large degree

What could make the guideline more suitable for your needs?

To what degree do you think the guideline could help you to implement sustainable web design practices?

To no degree
To some degree
Neutral
To a big degree
To a large degree

Question for Academia: Could the guidelines be a valuable addition to the sustainability syllabus of any of your study program courses?
This element is only shown when the option 'Academia' is selected in the question 'What is your current role?'

Any other feedback or comments you would like to add?

G Interactive Checklist Tool - URL Generator

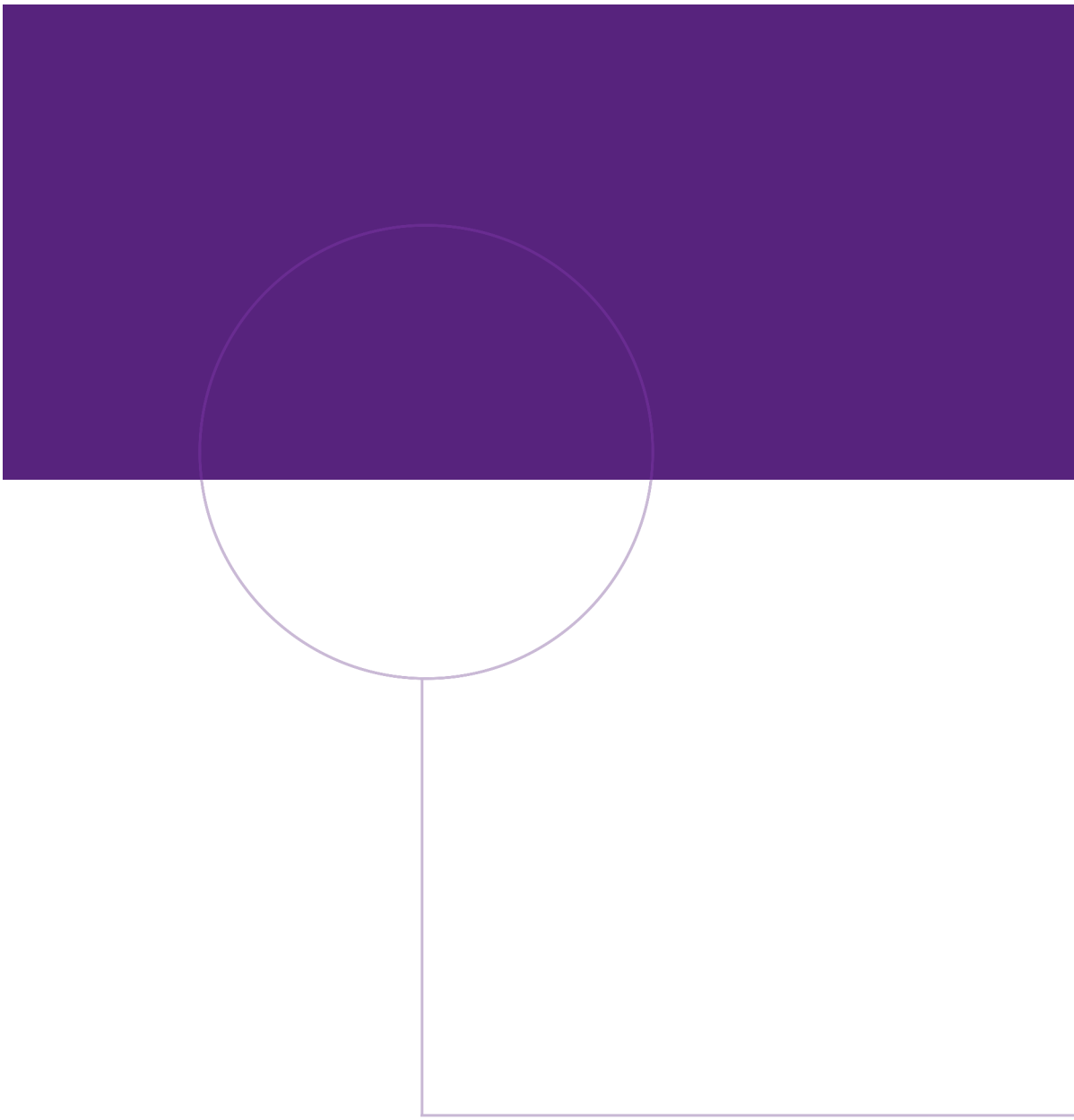
This appendix includes the code used to generate a custom URL for the Interactive Checklist Tool, as explained in Interactive Checklist Tool.

```
useEffect(() => {
  // Initialize empty objects and arrays.
  const c = {};
  const p = {};
  const urlCats = [];
  const urlPosts = [];

  // Define an async function that performs some operations on the URL query parameters.
  const funny = async () => {
    // Check if the URL query parameters exist.
    if (params) {
      // Decode and decompress the URL query parameters and split them into an array.
      const decodedParams = Buffer.from(
        await decompress(Buffer.from(decodeURIComponent(params), "base64"))
      ).toString();
      const arr = decodedParams.split("-");
      // Loop through each value of the array and push it to either urlCats or urlPosts array depending on whether it contains a "." character.
      arr.forEach((value) => {
        !value.includes(".")
          ? urlCats.push(getCategoryNameFromChapter(value))
          : urlPosts.push(value);
      });
    }

    // Loop through each key of the cats object and check if it exists in the urlCats array.
```

```
26      // Set the value of the corresponding key in the c object to an
            object with opened and checked properties.
27      Object.keys(cats).forEach((cat) => {
28        const here = urlCats.indexOf(cat) != -1 ? true : false;
29        c[cat] = { opened: here, checked: here };
30        p[cat] = {};
31      });
32
33      // Set the state of the categoryInfo object to a copy of the c
            object.
34      setCategoryInfo(() => ({ ...c }));
35
36      // Loop through all posts and check if the category or chapter of
            each post is in either the urlCats or urlPosts array.
37      // Set the opened property of the corresponding category to true if
            a post is found.
38      // Set the corresponding property of the corresponding chapter in
            the p object to true if a post is found.
39      allPosts.forEach((post) => {
40        const here =
41          (urlCats.indexOf(post.category) != -1 ? true : false) ||
42          (urlPosts.indexOf(post.chapter.toString()) != -1 ? true : false)
                ;
43        here && (c[post.category].opened = true);
44
45        p[post.category][post.chapter] = here;
46      });
47      // Set the state of the checkBoxes object to a copy of the p object.
48      setCheckBoxes(() => ({ ...p }));
49    };
50
51    // Call the funny function.
52    funny();
53
54  }, []);
```



NTNU

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