Master's thesis

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"Sustainable BizDevOps": A Novel Methodology for Reducing the Carbon Footprint of Web Products

Master's thesis in Applied Computer Science
Supervisor: Johanna Johansen
Co-supervisor: Nina Tvenge
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Abstract

In an increasingly connected world, web-based applications have become essential, offering convenience and cost savings for both individuals and businesses. However, these solutions are transmitting tremendous amounts of data over the internet, which comes at an environmental cost. The Information and Communications Technology (ICT) sector contributes to significant carbon emissions, due to its high electricity demand. If we are to meet the goals of the Paris Agreement, emissions must be cut across all industries, including the ICT sector.

This Master's thesis explores the carbon footprint of the web, and investigates strategies to reduce the footprint of web products, recognizing a lack in practical and comprehensive guidelines specifically targeting this issue. To address this, a novel methodology - Sustainable BizDevOps - is proposed. This methodology merges widely adopted principles from DevOps and BizDevOps approaches, coupled with insights from a literature review, focus group discussions, and semi-structured interviews with professionals. Sustainable BizDevOps offers concrete actions to be adopted throughout the life cycle of developing sustainable web products.

The study employed qualitative research methods, more specifically grounded theory. The empirical study aimed at gathering qualitative data in form of valuable insights into participants' experiences, perspectives, and opinions. Through a systematic and iterative process of coding, data gathering and analysis, several actions for sustainable web development and operations were identified. Participants were selected based on their expertise, ensuring a diverse and knowledgeable group of professionals.

Aiming to provide a set of practical solutions and raising awareness about the environmental impact of the web and its services, this study presents Sustainable BizDevOps as a potential catalyst for professionals to embrace more sustainable practices in web product development and operation. By stimulating further research and advocating for actionable steps, this work aspires to influence a path forward that aligns the digital industry with sustainable environmental practices.

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Chapter 1

Introduction

The widespread adoption of digital technology has led to both opportunities and challenges. In fact, digitalization has contributed to increased global energy consumption [1], which comes at an environmental cost. One of the findings from the literature review of this thesis, which is presented in Chapter 2, is the striking fact that the Information and Communications Technology (ICT) sector emits as much CO_2 annually as Germany, highlighting the need to address the environmental impact of this rapidly growing field. Within the vast ICT sector, this project focuses on web technology, specifically exploring ways to reduce the carbon footprint of web products. The field of sustainable web development is still emerging [2], gradually gaining recognition in both the academic field and the professional community. There is currently limited scientific literature on concrete measures to reduce the carbon footprint of the web, as explained in Chapter 2. On a positive note, the web development community has engaged in discussions around this. However, there is currently no set of universally accepted recommendations or guidelines for sustainable web development. This thesis delves into these pressing issues and seeks to contribute to the development of sustainable practices in web development.

This chapter provides an overview of the motivation, topic, problem and research questions of the study, in addition to a guide to the thesis outline. The chapter aims to clearly and concisely outline the objectives and goals of the study, place it in context, and provide a roadmap for the reader. The information presented in this chapter serves as the foundation for the rest of the thesis.

1.1 Motivation

As global initiatives like the Sustainable Development Goals (SDGs)[1] highlight the growing emphasis on environmental sustainability, it is clear that examining sustainable practices across various fields, including web development, is more important than ever. This study found no existing research proposing compre-

[1] https://sdgs.un.org/goals

hensive measures that can be applied throughout the development life cycle of web products. However, certain methods for specific use cases were discovered, and are presented in Chapter 2. Likewise, initiatives started by the industry are also presented in Chapter 2. The latter, however, could be better supported by research, in order to allow practitioners to create more environmentally-friendly web products.

A significant development is the increased focus on sustainability in the education sector, reflecting a larger social movement towards a greener future. As an example, sustainability is one of the strategic research areas at Norwegian University of Science and Technology (NTNU)[2]. The integration of sustainable principles has gained importance across a range of fields, from engineering and architecture to business and economics. Educational institutions contribute to cultivating a new generation of professionals by incorporating sustainability into curriculum and research, giving them the tools they need to address urgent environmental issues.

Several organizations already promote environmental sustainability within the field of web technology through declarations, manifests, guidelines and standards. Some of these, such as Wholegrain Digital[3] and The Green Web Foundation[4], further presented in Chapter 2, offer guidance to other businesses so they can become more environmental responsible. In turn, Increasing corporate environmental responsibility may lead to competitive advantages and increased firm value [3].

My growing interest in environmental sustainability, web development and project management, along with my academic background and professional network, were major factors contributing to the selection of this topic for the master's thesis. The completion of various courses, such as "IMT4887 - Specialisation in Web Technology"[5] and "IMT4134 - Specialisation in Software Engineering"[6] at NTNU have deepened my understanding of sustainability within web technology and software engineering, fueling the drive to pursue this self-defined research project. Additionally, my professional network includes several individuals who can provide guidance and data for the project, making it a unique opportunity to contribute to the field. My current employer, Telenor Norge, has in recent years increased focus on environmental sustainability. Through one of the interviews of this study, with one of the technology managers in Telenor, I learned that the company has been modernizing their IT systems and migrating to cloud services that are running on renewable energy. This real-world application underscores the relevance and practicality of this study's focus, highlighting the ongoing adoption of sustainable practices within the industry.

[2] https://www.ntnu.edu/sustainability
[3] https://www.wholegraindigital.com/
[4] https://www.thegreenwebfoundation.org/
[5] https://www.ntnu.edu/studies/courses/IMT4887
[6] https://www.ntnu.edu/studies/courses/IMT4134

1.2 Topic

Existing studies have shown that the oil and transportation industries contribute significantly to the world's greenhouse gas emissions, underscoring the importance of taking action to reduce their carbon footprint [4, 5]. However, it is easy to forget that the very biggest companies today do not trade in material goods, but data. Companies like Meta and Google for instance, how are they impacting the environment? They are not spewing out black smoke or directly producing pollution, but they require a lot of energy to work. Since a substantial percentage of the world's energy is still produced by burning fossil fuels, and data centers are one of the fastest growing sources of electricity demand [6], the operation of data centers are now one of the biggest threats against our chances of reaching the goals of the Paris Agreement[7].

The environmental sustainability of the internet itself is a broad topic, factoring in the operation of data centers, telecommunication networks, and end devices. Therefore, by employing the methods outlined in Chapter 3, the scope of the topic is refined to concentrate on the adaptations required in the development and operations of web products to ensure a reduction in their carbon footprint.

1.3 Problem

The specific problem that this study aims to address, as already briefly introduced, is the fact that web products such as web applications and websites do contribute to global emissions, which in turn play a role in global climate change [2, 6]. The way web products are developed and operated directly influence their carbon footprint [7–10]. Therefore, this research project aims on identifying the factors within these processes that contribute to emissions and discovering ways to minimize this impact. Chapter 3 presents the research methods that were used to define and specify the current research problem.

1.4 Research Questions

The research questions guiding this study were chosen to address the sustainability challenges related to web products, by suggesting improvements in the development and operation processes. The first research question is focused on establishing a background and gaining an understanding of the current state of the literature in this field. The second research question builds upon the insights gained from the first question and is more specific, as it seeks to provide practical recommendations for reducing the carbon footprint of web products. By addressing these questions, this study aims to contribute to the development of more sustainable practices in web product development and operation.

[7] Paris Agreement - UNFCCC (link)

- **Research question 1:** What is the current status on the sustainability of the web, and what are common practices in the development and operation of web products today?
- **Research question 2:** What principles and practices should be incorporated into an environmentally sustainable methodology for the development and operation of web products?

Contribution to the Field

One contribution of this thesis is a literature review, presented in Chapter 2. This review provides an assessment of current and projected CO_2-emissions from the ICT sector, thereby highlighting the significant environmental impact of the sector. In addition, an exploration of academic resources identifies strategies for reducing the impact, with emphasis on how organizations can create web products with lower footprints. Several actions were discovered, both at management level and at development level. As the second research question aims at developing a methodology for reduced carbon footprint of web products, the review also examines practices in the development and operations of web products, with special emphasis on the DevOps approach.

The main contribution of the thesis is the development of a novel methodology for reducing the carbon footprint of web products. Being based on the DevOps methodology, who many professionals already are experienced with, it aims to be easy adoptable, with straightforward guidelines that can be employed at several phases of the development life cycle.

1.5 Thesis Outline

The rest of the thesis follows the outline below:

Chapter 2: Background thoroughly presents the current state of research regarding environmental sustainability in the ICT sector and web technology. Furthermore, various project management methodologies are discussed, including DevOps, a widely recognized and customized approach. The aim of this chapter is to provide an overview of the existing knowledge in these fields and lay the foundation for the rest of the project to build upon.

Chapter 3: Defining the Problem presents the process of defining and scoping the research project. Then, the process of gathering and selecting literature for the background section is described.

Chapter 4: Method covers the procedures for data collection, along with building and running the study. Moreover, the ethical considerations relevant to this study are presented.

Chapter 5: Results presents the data analysis process. By employing a grounded theory approach, the results are formed through a systematic and iterative

process of coding, data gathering and analysis. It provides tables to visualize the process.

Chapter 6: Discussion delves into the proposed methodology, detailing its various phases and the associated guidelines. It also bridges the gap between the empirical data and the resulting methodology, and examines the limitations of the study, enhancing the transparency and validity of the research.

Chapter 7: Conclusion rounds off the thesis by summarizing the key findings, along with suggestions for potential future research.

Chapter 2

Background

In order to provide an overview of existing knowledge and practices related to this thesis, this chapter is divided in three sections.

The first section describes the metrics used for measuring and describing the sustainability of the internet and its services. This knowledge is necessary for understanding the measurements of web sustainability.

Next, current research is examined to gain insights into the environmental sustainability of the ICT sector and the web. Specific techniques and technologies used in web development that may reduce carbon emissions are revealed, as well as in- dustry standards and guidelines.

The last part of this chapter covers project management methodologies, with emphasis on agile methods and DevOps. The values and principles of existing and well known methodologies may be used as reference points when developing new methodologies.

2.1 Metrics for Measuring Web Sustainability

Measuring the sustainability of the internet is a complex task, due to the absence of a unified metric to evaluate either internet sustainability or the sustainability of web products. However, according to researchers, some commonly used indicators to measure the CO_2 produced by web products include: *data transfer*, *carbon intensity of electricity*, and the *energy consumption* of data centers and network infrastructure [6, 11, 12].

Data transfer is measured in data size, usually in kilobytes (kB) or megabytes (MB). When evaluating web pages, *page weight* is a useful metric, meaning the transfer size of web pages at initial load.

Carbon intensity of electricity equals the amount of CO_2 produced for every kilowatt-hour of electricity, and is measured in gCO_2/kWh [11, 13]. Typically, renewable energy sources and nuclear energy have less than 10 gCO_2/kWh, whereas energy generated by burning fossil fuels has a carbon intencity of between 200-400 gCO_2/kWh [11].

The significance of these two metrics lies in their connection with the third metric, *energy consumption*. By knowing the energy consumption, typically measured in TWh (Terawatt-Hours) per year for data centers and network infrastructure [14], one can estimate the carbon footprint of that energy usage. In general, these metrics collectively enable the calculation of the carbon footprint of the internet and its services.

In the context of this study, the understanding and application of these metrics are essential. They form the basis for evaluating the environmental impact of the ICT sector, as part of the next section.

2.2 Web Sustainability

2.2.1 Status on Web Sustainability

Many researchers have been attempting to calculate the power consumption and carbon footprint of the Internet, with various approaches and great variation.

According to Malmodin, a researcher at Ericsson[1] who has published multiple papers on ICT sustainability [15–17], the carbon footprint of the ICT sector peaked in 2010 and has been declining ever since, compared to the global carbon footprint [17]. He states that between 2005 and 2015, global data traffic has increased around 30 times, while server efficiency has increased 100-fold over the same period [16] indicating that the total footprint of the ICT sector are decreasing. Furthermore, he suggested a new way to estimate electricity usage of the Internet, looking at energy per time instead of per data, like other researchers have done.

Andrae, a researcher at Huawei[2], has also released multiple papers in this domain [6, 18–20]. In his 2020 paper "New perspectives on Internet electricity use in 2030", he forecast the required energy to power the ICT sector. He found that his estimates were lower than his previous findings [18]. The reason for this is the continuously improvements in electricity intensity for most entities within ICT. Data centers are and will be more energy efficient, by for example utilizing excess heat. Consumer devices and battery technology are evolving and becoming more energy efficient. He stated that in 2020, the ICT sector accounted for up to 7% of the total global electricity use. Then he pointed out that the overall electricity use of the ICT sector cannot and will not slow down until 2030. Andrae concluded that the entire energy consumption of the ICT sector in 2020 was around 1990 TWh, and predicted the total for 2030 to be 3200 TWh. Thus, in contrast to Malmodin, Andrae suggest that the ICT industry has and will continue to have a considerable share of the global electricity footprint [18].

Obringer et al. published a paper in 2021 on the carbon footprint of increased Internet usage, especially during the COVID-19 crisis. They highlighted the increased data transfer coming from online meetings through services like Teams and Zoom, and estimated that the increased Internet usage in 2021 could cause

[1] Ericsson.com

[2] Huawei.com

the global carbon footprint to grow by 34.3 million tons of CO_2, if remote work continued throughout that year [21].

In their 2022 study, Scarlat et al. quantified the carbon intensity of the electricity produced and used in Europe. As mentioned in Section 2.1, this metric is essential when calculating the carbon footprint of an industry. Scarlat et al. found that there are significant variations between countries, and the trend shows a clear reduction since 1990. The carbon intensity of electricity used in the European Union at low voltage decreased from 641 CO_2 equivalent emissions per KWh (gCO_2eq/kWh) in 1990 to 334 gCO2eq/kWh in 2019, and is expected to follow the same pattern in the years to come [13].

By using the data above from existing research, we can estimate the amount of CO_2 emitted by the ICT industry. Using Andrae's estimations of 1990 TWh for 2020 and 3200 TWh for 2030 [18], along with Scarlat et al.'s findings for carbon intensity of electricity in Europe [13], the following calculation can be made to estimate the current global footprint (given that the European carbon intensity is similar to the global value):

$$\begin{gathered} 1990 \text{ TWh} = 1.99 \times 10^{12} \text{ kWh}. \\ 334 \text{ gCO}_2\text{eq/kWh} \times (\ 1.99 \times 10^{12} \text{ kWh}\ ) = 6.6466 \times 10^{14} \text{ gCO}_2 \\ = 6.6466 \times 10^{8} \text{ tons of CO}_2 \\ = 664.660 \text{ million tons of CO}_2 \end{gathered}$$

Based on these calculations, the entire ICT sector's annual emissions are equivalent to those produced annually by Germany, which is approximately 665.88 million tons of CO_2, according to the latest report from the European Commission [22]. This is equivalent to 1.76% of the world's total emissions [22].

Assuming that carbon intensity will follow the pattern presented in [13], an estimated carbon intensity of 250 gCO2eq/kWh is likely in 2030. The estimated emissions of the ICT sector in 2030 can therefore be calculated as following:

$$\begin{gathered} 3200 \text{ TWh} = 3.2 \times 10^{12} \text{ kWh}. \\ 250 \text{ gCO}_2\text{eq/kWh} \times (\ 3.2 \times 10^{12} \text{ kWh}\ ) = 8 \times 10^{14} \text{ gCO}_2 \\ = 8 \times 10^{8} \text{ tons of CO}_2 \\ = 800 \text{ million tons of CO}_2 \end{gathered}$$

800 million tons of CO_2 is still likely to be a relatively modest percentage of the total global emissions, as confirmed by Andrae [20]. However, Belkhir et al. assumed in 2018 that ICT will account for around 14% of global emissions in 2040 [12]. Existing literature on estimations for ICT global emissions is very limited. In 2013, Malmodin et al. forecasted the ICT footprint to exceed 1 billion tons of CO_2 by 2020 [15] and Andrae et al.'s data suggested a value of 3.4 billion tons CO_2 by 2030 [6]. All available research points in the direction that emissions from the ICT sector will increase, but the estimates vary greatly.

Fundamentally, this brings attention to the notable emissions generated by the ICT sector, both currently and in the future, emphasizing the need to minimize them through embracing sustainable energy sources and moderating energy

consumption. Separating the ICT sector to solely measure the environmental footprint of the Internet has proven to be challenging, given that the internet relies on interconnected components, including data centers, communication networks, and devices [2].

2.2.2 Strategies to Improve Web Sustainability

In order to enhance the environmental sustainability of the web and its products, it may be beneficial to consider various levels of the value chain, from management levels to individual developers. This involves not only exploring theoretical concepts but also examining existing real-world solutions and methodologies that can be applied to the field of web technology. Section 3.1 explains in detail why community practices are important to factor in, complementing available research. With this comprehensive approach, this section aims to provide an overview of strategies, derived from both research papers and practitioner communities, that could be employed to create a more sustainable web ecosystem.

Prioritizing Sustainability at Management Level:

Several actions can be taken at management levels in organisations, in order to reduce the energy consumption and the carbon intensity of electricity of the web products they deliver.

A significant consideration for organizations aiming to improve their environmental sustainability is the adoption of green energy sources [1, 11]. While it might be difficult to manage the energy sources used by communication networks and user devices, organizations can make informed choices by selecting service providers that prioritize or commit to using renewable energy sources for their data centers. Some of the biggest hosting providers, such as Google[3] and Microsoft Azure[4], have now committed to sustainable technologies and renewable energy sources.

If an organization was to host its web products on their own servers, implementing energy-efficient actions on the data center may reduce energy consumption significantly. The Lawrence Berkeley National Laboratory in California has established a "Center of Expertise for Energy Efficiency in Data Centers", which published a comprehensive list of recommended efficiency actions in 2016 [23]. The list includes essential actions such as optimizing cooling systems, using virtualization technology to reduce server **sprawl**[5], and implementing server power management. Hintemann et al. also point out the importance of improving energy efficiency on IT components in data centers in order to reduce their carbon footprint [14].

Setting sustainability goals and tracking progress through Key Performance Indicators (KPIs) has been proven to be effective ways of prioritizing sustainabil-

[3] `https://sustainability.google/`

[4] `https://azure.microsoft.com/en-us/explore/global-infrastructure/sustainability/`

[5] Describe

ity at management levels [24, 25]. Moreover, science-based targets [26–28] and the Sustainable Development Goals (SDGs) [29, 30] have been used to help companies implement and reach their sustainability targets. Additionally, researchers have explored the role of business models for sustainability [31] and developed typologies to clarify the meaning of sustainable business [32], further guiding companies in their pursuit of sustainable practices.

Management can encourage employee awareness and engagement in sustainability initiatives to create a culture of environmental responsibility [33]. Clear communication of the organization's sustainability vision, along with the integration of this vision into the company's mission and values, can help align employees' goals with sustainability objectives. Also, providing training, resources, and support may empower employees to actively participate in sustainability initiatives [33].

Other ways to increase corporate focus on sustainability include following standards, requirements, or guidelines set by governments or organizations, such as The International Organization for Standardization[6] (ISO) [34] or The World Wide Web Consortium[7] (W3C). These approaches are further explained in Section 2.2.3. Besides ISO and W3C, there are multiple independent organizations that offer solutions and help to businesses in order to improve their environmental sustainability. Some of them are:

- Wholegrain Digital (British)[8]: A web design agency focusing on creating sustainable websites and digital solutions, offering energy-efficient web development, eco-friendly web hosting, and consultancy services for sustainable digital transformation. Along with the American agency Mightybytes[9], Wholegrain Digital co-developed "Sustainable Web Design"[10], a guidebook that provides resources, guidelines, and best practices for designing and developing sustainable websites that minimize energy consumption and environmental impact. They also developed "Website Carbon"[11], a website that allows users to measure the carbon footprint of their websites and provides recommendations for reducing their carbon emissions. Additionally, Wholegrain Digital created the "Sustainable Web Manifesto"[12], which outlines a set of principles and commitments for designing and developing a more sustainable web. As of today, the manifesto has been signed by over 2800 individuals and organizations in the web industry who are committed to reducing the carbon footprint of their online presence.
- The Carbon Trust (British)[13]: A global organization that helps businesses, governments, and institutions reduce their carbon footprint and transition

[6] ISO
[7] W3C
[8] https://www.wholegraindigital.com/
[9] https://www.mightybytes.com/
[10] https://sustainablewebdesign.org/
[11] https://www.websitecarbon.com/
[12] https://www.sustainablewebmanifesto.com/
[13] https://www.carbontrust.com/en-eu

to a low-carbon economy. They offer a range of services, including carbon footprint assessments, energy-saving advice, and certification for carbon reduction and sustainability initiatives.
- The Green Web Foundation (Dutch)[14]: an organization that promotes the transition to a greener internet. With the goal of achieving a fossil-free internet by 2030, the foundation actively tracks and accelerates this transition by providing an open dataset of websites operating on renewable energy, which has been accessed over 2 billion times. They offer tools and resources to assist organizations in adopting more eco-friendly internet practices, while also advocating for a more sustainable and fair internet.
- ClimateCare (British)[15]: Offers carbon offsetting programs, climate and development projects, and consultancy services for organizations in various sectors, including ICT and web technology, to reduce their carbon footprint and support sustainable development.
- RESET (International)[16]: Promotes digital and environmental sustainability by supporting ICT projects and startups focused on reducing energy consumption, increasing energy efficiency, and creating a positive environmental impact.

Prioritizing Sustainability at the Development Level:

Software developers can employ various techniques and best practices to create web products with reduced carbon footprint and potentially enhance their performance. This section explores a range of strategies aimed at minimizing the resource usage of websites and applications, contributing to a more sustainable web environment. Reducing data transfer is one of the main measures that need to be taken, and developers can directly influence this by reducing the weight of websites and apps [11], as mentioned in 2.1. By emphasizing sustainability during the development process, developers can proactively address environmental concerns while simultaneously optimizing the functionality and user experience of their web products.

One of the most effective strategies developers can employ to reduce the weight of their web products is the optimization and compression of assets. By decreasing file sizes of images, scripts, and stylesheets, developers can facilitate faster page load times and reduce bandwidth consumption [10, 11, 35]. Implementing techniques such as minification, compression, and image optimization can significantly contribute to these improvements [10, 11, 35]. For instance, utilizing the WEBP image format, which is typically 30% smaller than JPEG images, can further enhance web product efficiency [11].

Pavić and Brkić explored several additional techniques that can be utilized to enhance performance and decrease data transfer in React Web-applications [10]:

[14] `https://www.thegreenwebfoundation.org/`
[15] `https://climatecare.org/`
[16] `https://reset.org/`

1. Code splitting: This involves dividing large files into smaller, more manageable files that can be loaded on-demand as required, rather than loading entire scripts upfront. This approach allows for more efficient resource usage and faster load times.
2. Tree shaking: This technique helps reduce the overall application size by removing unused code from the final build, thus optimizing the web product and minimizing resource consumption.
3. Server-side rendering (SSR): With SSR, a web page's HTML is generated on the server and sent to the client, resulting in quicker initial load times and improved search engine optimization (SEO) [10]. The client's JavaScript then assumes control, enabling interactive features and dynamic page changes. Using SSR can reduce a website's energy consumption since the client's device does not have to perform as much processing [10].
4. React frameworks: Pavić and Brkić highlight Next.js[17] as a framework that has many build in features, such as those mentioned above [10].

A well-documented and effective technique for reducing data transfer and energy consumption in web applications is the utilization of efficient caching strategies, because they significantly decrease the need for repetitive server requests, as they store and reuse frequently requested data [36]. By implementing proper caching mechanisms, developers can minimize the need for users to download redundant data, thereby optimizing both server and client-side resource usage [11, 35, 36]. Efficient caching techniques include browser caching, which stores static files locally on the user's device, and server-side caching, which retains frequently requested data in the server's memory. These approaches help decrease server load, network latency, and bandwidth consumption, resulting in improved user experience, faster load times, and reduced energy consumption [11, 35, 36].

Content delivery network (CDN) is a system of distributed servers that are located in various geographic locations. The primary goal of these servers is to improve the delivery speed of web content to users by reducing the physical distance between the server and the client. Tom Greenwood points out some advantages of using a CDN when fetching content or libraries from the web. First of all, shorter distance between server and client result in less stress on the network and therefore an energy reduction. In addition, developers and companies can choose between various CDN providers, and may opt for a service that runs on renewable energy [11].

By postponing the loading of non-critical resources until they are needed, developers can reduce initial page load times and conserve bandwidth. This technique is named lazy loading, and can significantly reduce response times [10, 35, 37]. As an example, in a web page, a placeholder image can be displayed until the user scrolls down to where the full image is located, at which point the full image is then loaded [37]. This technique contributes to a reduction of data transmitted

[17] `https://nextjs.org/`

on initial page load, reducing page weight.

While the previously mentioned examples represent individual solutions, Progressive Web Applications (PWAs) incorporates several such solutions into one unified framework. PWAs represent a hybrid approach to web development that seeks to integrate the most advantageous features of both web and native applications. By employing many of the techniques mentioned earlier, such as efficient caching, code splitting, and server-side rendering, PWAs can achieve faster, more reliable, and secure web experiences while simultaneously promoting energy efficiency [11, 36, 38]. In addition to these benefits, PWAs also offer features typically associated with native apps, such as offline functionality, push notifications, and the ability to be installed on a user's device, providing a seamless and engaging user experience [36]. In terms of sustainability, PWAs contribute to less data transfer by caching key information and assets on client devices [38, 39].

To build a functioning PWA, two key technologies are required: a service worker and a web app manifest. A service worker is a JavaScript file running in the background, enabling features like offline functionality and push notifications [38]. Meanwhile, the web app manifest is a JSON file providing metadata about the web application, such as its name and icons. It helps present the web application as a native-like app when installed on a user's device [39, 40].

Wholegrain Digital and Mightybytes emphasize the importance of writing reusable code in their online guidebook as a key recommendation for sustainable web development [41].

One of the key suggestions presented by Wholegrain Digital and Mightybytes in their online guidebook, is to write reusable code [41]. Writing code that is easy to understand will also make it easier to maintain, and can also save time and effort in the development process [41].

Koedijk et al.'s 2022 paper presents a noteworthy analysis of the differences in energy consumption among various programming languages. Their findings highlight the significant impact of both the choice of language and its implementation on the energy consumption of the resulting products. Although the study included only PHP and JavaScript as web-oriented languages, the outcomes were rather complex. For instance, lightweight PHP programs outperformed lightweight JavaScript programs in terms of speed, while the opposite was true for heavier programs [9]. This underscores the importance of considering the specific context and requirements of a web project when selecting a programming language and optimizing its implementation for energy efficiency.

Additionally, De Macedo et al. conducted a comparison between JavaScript and WebAssembly, the latter of which executes code more quickly and does not rely on a JavaScript engine within the browser. Their preliminary findings indicate that WebAssembly, despite being in its early stages, is beginning to surpass JavaScript in terms of performance [7, 8]. This suggests that WebAssembly may offer developers a promising alternative for creating efficient and high-performing web applications as the technology continues to mature.

In conclusion, although each of the actions mentioned above may individually

result in a modest reduction in data transfer and electricity usage, their cumulative impact has the potential to be significant. Considering the vast user base and widespread adoption of web products, small improvements made by numerous developers can lead to notable aggregate benefits in terms of energy efficiency and environmental sustainability. By further exploring and adopting these sustainable practices and technologies, the web development community can work towards a more sustainable web.

2.2.3 Industry Standards / Guidelines

The sections above have demonstrated that existing research highlights considerable opportunities for environmental sustainability improvements within the ICT sector and the web. Furthermore, numerous techniques and development methods have been identified to promote and ensure a more sustainable web. However, research on how and why companies should tackle these challenges to reduce their carbon footprint is limited. Therefore, examining industry standards and requirements could be beneficial in guiding organizations towards adopting sustainable practices and achieving a more eco-friendly web.

ISO and W3C are two leading international organizations that develop and promote standards, requirements, and guidelines for numerous aspects of the digital world, including web technologies and environmental sustainability. There are several reasons why companies should follow the standards and requirements formulated by these organizations. First, compliance with these standards ensures compatibility and seamless integration between various systems, enhancing overall functionality and user experience [42]. Second, compliance to W3C and ISO standards can enhance a company's reputation and credibility, as it indicates their dedication to best practices and responsible development [43, 44]. Lastly, in certain situations, companies might be legally obligated to observe specific standards or guidelines, especially when dealing with accessibility, privacy, or data protection [45, 46].

ISO has established several committees that work in specific fields, one of which is "ISO/TC 207" that is dedicated to environmental management. This committee has published a wide range of standards. According to the chair of the committee, Sheila Leggett, at least 14 of the 17 SDGs are directly or indirectly addressed by their work [47]. Furthermore, she states that their "vision is that the implementation of the ISO 14000 standards offers a significant and positive contribution to achieving/delivering the SDGs" [47]. Another committee that is directly focused on sustainability, is "ISO/IEC JTC 1/SC 39 - Sustainability, IT and data centres"[18]. They have published 28 standards and are currently working on 6 more. Their primary focus appears to be on environmentally sustainable data centers, as this is the subject of 27 published standards and of 5 that are currently in development. It may be worth noting that none of these standards seem to be specifically geared towards development techniques.

[18]ISO/IEC JTC 1/SC 39 - Sustainability, IT and data centres

Some of the standards developed by ISO that could help IT and web-development businesses increase awareness and improve on environmental sustainability are:

- *ISO 26000 - Social responsibility [44]:* Provides guidance on how businesses and organizations can operate in a socially responsible manner, which encompasses sustainable environmental practices. In the context of the web industry, it encourages companies to adopt environmentally responsible behaviors like energy-efficient solutions and limit resource usage.
- *ISO 14001 - Environmental management [48]:* Focused on environmental management, this standard aids organizations in minimizing their environmental impact and continuously improving their environmental performance.
- *ISO 50001 - Energy management [49]:* Provides a model for companies to follow when setting up an energy management system, that will help manage energy supply and making better use of energy consumption.
- *ISO/IEC 38500:2015 - Governance of IT for the organization [43]:* Provides principles, definitions, and a model for the governance of IT, including the management of its environmental impact, on an organizational level

W3C has taken a different approach, addressing various aspects of web development, including accessibility, performance, and security. The organization operates as an international community that hosts several "community groups". The "Sustainable Web Design Community Group", created in 2013, unites professionals from around the world who are dedicated to building a more sustainable web [50]. Together, they share up-to-date knowledge and information on sustainable web design and are currently collaborating on a set of guidelines to help web teams develop environmentally friendly digital products and services [51].

By considering both ISO standards and W3C guidelines, developers and businesses can gain a comprehensive understanding of both broad and specific strategies to reduce energy consumption. ISO standards provide internationally recognized frameworks for a wide range of sustainable practices, while W3C initiatives are more specific and tailored for the web industry. In the context of this research, ISO standards may be relevant for building a culture for sustainability, while initiatives from W3C can serve as guidelines.

2.3 Project Management Methodologies Related to Web Development

To start of with, a project management methodology is defined by Adobe as "a set of guiding principles and processes used to plan, manage, and execute projects" [52]. They also highlight that the selection of methodology will affect how tasks are prioritized and finished. Most software engineering teams today work in an agile manner, meaning that tasks are broken up in phases that iterate in order to ensure continuous improvement and close collaboration with stakeholders [53].

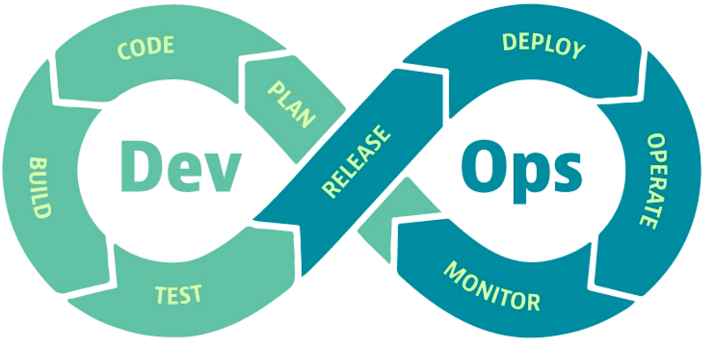

Figure 2.1: Illustration of the DevOps methodology.

DevOps

Numerous methodologies exist for managing and organizing web product development, with the DevOps (Figure 2.1) approach proving to be a successful choice for enhancing the efficiency of web teams [54–56]. DevOps takes project management methodologies to a new level, by promoting closer collaboration between developers (Dev) and operators (Ops) [57]. Leite et al. conducted a comprehensive survey of the concepts and challenges of DevOps in 2019, considering all relevant research up until then, and is therefore frequently cited in this section. Since there seems to be no common definition of DevOps [56, 58], they also consolidated the most cited definitions of DevOps, and crafted their own that reads:

> "*DevOps is a collaborative and multidisciplinary effort within an organization to automate continuous delivery of new software versions, while guaranteeing their correctness and reliability*" *[57]*

The DevOps-movement emerged in 2008, when developers and operators discovered that the gap between the two "silos" led to significant deployment times and infrequent and unreliable releases [57]. Today, DevOps plays a central role in lots of well established software engineering organizations and contribute to more efficient development and operation [56]. It has also been proved that the gaps between the silos have been significantly reduced [57]. By surveying most current literature on DevOps, Leite et al. concluded that there are three main ways of adopting it successfully; "Collaborating departments", "Cross-functional teams", or "DevOps teams". The former advocates closer collaboration between the two "silos", overlapping necessary responsibilities. The "cross-functional team"-approach suggests a "do-it-all-team". In other words, "you built it, you run it". This approach is recommended by Amazon and Facebook. The final approach implies the assignment of a new team in between operators and developers, called a "DevOps team" [57].

Every organization has its own unique priorities and needs. This means they can pick and choose, adapt and use methodologies as they see fit, to get the results that match their specific requirements. As a result, many different versions of DevOps have emerged, each focusing on certain areas. Among these, the following variations may be relevant to web development, and have gained popularity due to their unique focus:

- **SecDevOps or DevSecOps (Figure 2.2):** This approach incorporates security practices into the DevOps life cycle, by incorporating a culture with security in focus. DevSecOps was first mentioned in 2012 [59], and has since then gained significant interest from both the industry and academia [60], as the importance of security is every increasing. It promotes a "security as code" culture where security considerations are integrated into the software development process from the beginning, rather than being treated as an afterthought [59–61].
- **BizDevOps / BizDev / BizDevSecOps (Figure 2.3):** This approach reinforce the collaboration between business, development, and operations, and promotes a culture were stakeholders are more involved with IT [62, 63]. While not being well documented in academic literature, it has gained interest in the industry. Diaz et al. found that in traditional DevOps, development teams collaborate closely with business-divisions, but too far from operation-teams, this caused friction between developers and operators and resulted in bad releases [56].
- **DevDocOps:** Recognizing the rapid acceleration of delivery and deployment frequencies in DevOps, Rong et al. proposed DevDocOps as a solution for generating supporting documentation at the same pace [64]. Their system, named iDoc, successfully automates the process of documentation, generating documents in mere minutes.

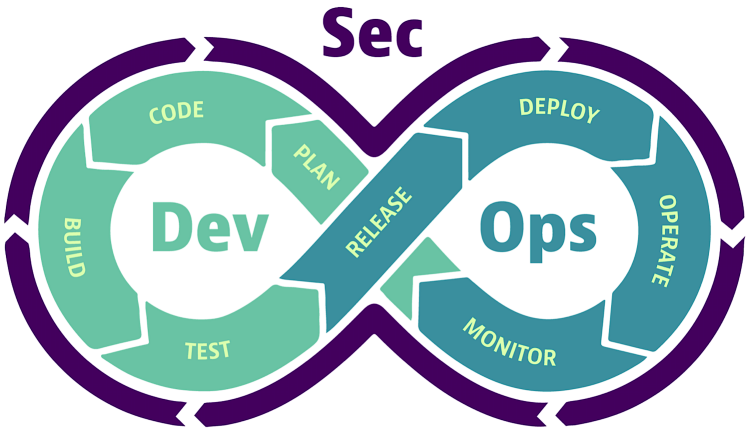

Figure 2.2: Illustration of the DevSecOps methodology.

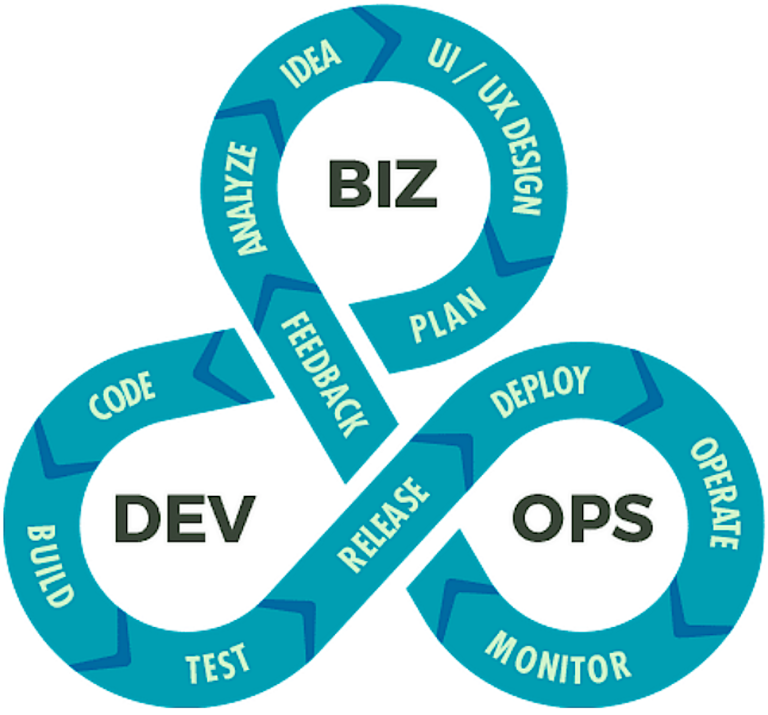

Figure 2.3: Illustration of the BizDevOps methodology.

Chapter 3

Defining the Problem

This chapter outlines the methodologies used when defining the project and gathering research for the background-section.

Topic

As mentioned in Chapter 1, the environmental sustainability of the internet is a vast topic. Therefore, this project has been narrowed down to be more specific, by adopting theoretical strategies. Booth et al. introduce methods to narrow down research topics [65]. By adding words and phrases that express actions or relationships, the topic is specified towards paths that can be pursued in a research project. In this case, the research topic is specified by clarifying what elements of internet sustainability that will be investigated:

Topic:
Internet sustainability $\rightarrow$ *The environmental sustainability of web products, and specific measures to reduce their impact*

Problem

As clarified above, the research topic that will be covered is specifically related to the carbon footprint of end products. Booth et al. [65] suggest a three-step formula to further specify research projects and identify their significance:

1. **Topic: The study investigates** the environmental sustainability of web products, and specific measures to reduce their impact.
2. **Question: because the objective is to find out** how the processes can become more environmentally sustainable.
3. **Significance: in order to help the readers to understand** how practitioners can contribute to achieving this.

Booth et al. mention that in order to make research matter to others, it is necessary to address research problems that not only the authors want to solve, but also the research community and the readers of the current work [65]. To enable this, it

is useful to define practical and conceptual problems that are relatable to most readers. Practical problems motivate research questions, which define conceptual problems. Conducting the research leads to a research answer that can help solve the practical problem [65]. Booth et al. illustrates this graphically as an iterative process, see figure 3.1.

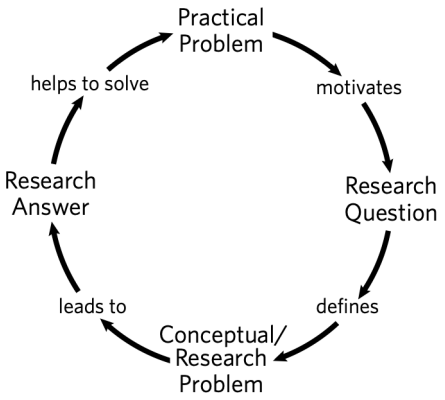

Figure 3.1: The relationship between practical and conceptual problems, as illustrated by Booth et al. [65]

Practical Problem

In general, a *practical problem* is a result of a situation that bothers us somehow. Either costing us time, money, respect, security, opportunity or lives [65]. A practical problem is solved by *doing* something that eliminates the unwanted outcomes. However, in order to know what to do, it is necessary to *understand* something better.

In this project, the **practical problem** is that web products contribute significantly to global emissions [6–11, 18, 19], which again play a role in global climate change.

Research Questions

Motivated by the practical problem, two research questions have been formed, playing an important role in shaping the research project and presenting the conceptual problem and challenge.

- **Research Question 1:** What is the current status on the sustainability of the web, and what are common practices in the development and operation of web products today?
- **Research Question 2:** What principles and practices should be incorporated into an environmentally sustainable methodology for the development and operation of web products?

Conceptual Problem

To acquire the knowledge needed to better understand how to solve the practical problem, a *conceptual problem* can be raised. As opposed to a practical problem, a conceptual problem requires further research that eventually leads to a better understanding of how to change something [65].

The **conceptual problem** of this project, is to develop a novel or modified working methodology that will reduce the carbon footprint of web products. The emissions of the end products, for instance web applications, are closely related to how they are developed and operated [7–11].

3.1 Literature Review

For this study, the literature review help substantiate the research problem. Therefore, unveiling the methods and approaches used for building the background chapter is included here. This includes collecting and examining the research. Sharing these methods aims to enhance the transparency of the project and strengthen its reliability. First, the buildup and organization of the literature review is presented, followed by the search and selection protocol.

The background section of the thesis presents a comprehensive review of relevant literature within three key areas. Firstly, metrics for measuring the carbon footprint of the web (Section 2.1) are explained. Secondly, a broad look at the environmental sustainability of the ICT sector and the web (Section 2.2) is provided, exploring the current status of web sustainability, potential strategies for improvement, and existing industry standards and guidelines. Finally, project management methodologies such as DevOps (Section 2.3) are examined, in order to understand how new methodologies can be developed.

Considering the rapidly evolving field of web development, the number of grey literature, white papers, and community publications in the field of sustainable and energy-efficient web development was far greater than the number of academic publications. Following Booth et al.'s recognition of the value of various types of sources [65], this thesis considers some non-academic resources. While primarily focused on academic publications, the study also engages with some grey literature, white papers, and community publications, which are referred to as footnotes in the background section. This approach acknowledges the need for further research in the field of sustainable web development, and opens a discussion that is further explored in the conclusion (Chapter 7).

3.1.1 Search and Selection Protocol

A search and selection protocol were established (see Figure 3.2), inspired by Budgen et al.'s specific guidelines on performing systematic literature reviews in software engineering [66]. Relevant literature was collected using two major aca-

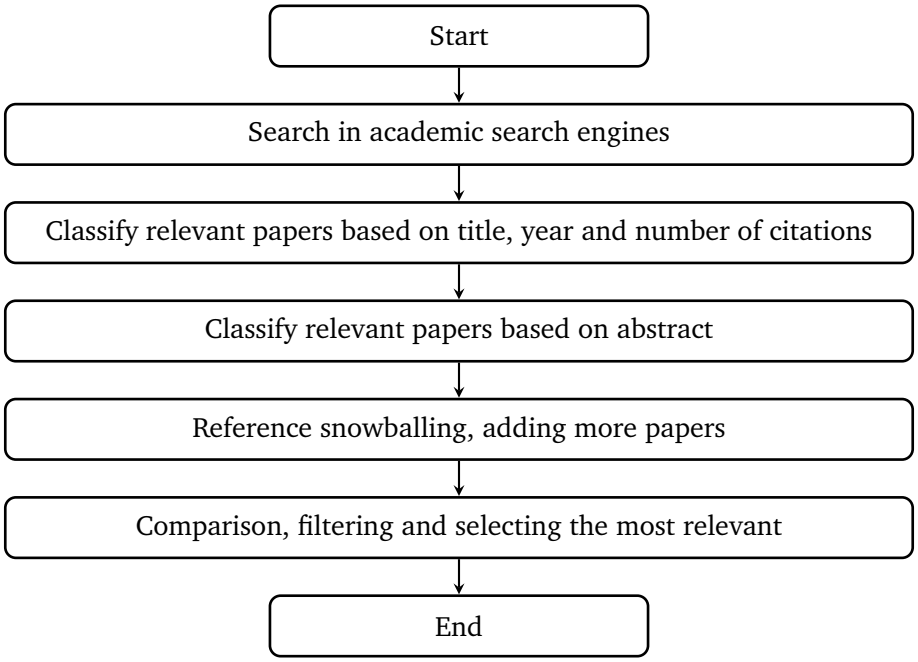

Figure 3.2: Illustration of the search and selection protocol, inspired by Budgen et al. [66].

demic search engines, Google Scholar[1] and IEEE Xplore[2]. These platforms were chosen due to their extensive repositories of scholarly articles and papers across diverse disciplines. Following the advice given by Booth et al. [65], two main criteria are used to evaluate sources: relevance and reliability. In general, searches were restricted to articles published in or after 2018 to ensure that the most recent research was considered. The direct relevance of each paper to the research questions, credibility of the authors and type of publication, were also taken into account while selecting the sources. Lastly, only papers written in English were included, and preference was given to papers with a high number of citations.

In addition to using search engines to identify relevant papers, a method known as snowballing was employed to enhance the effectiveness of the search for appropriate resources. Snowballing is a technique where the references within an already identified paper are exploited to discover additional related works [67]. In this study, two types of snowballing methods were used: backward and forward snowballing. Backward snowballing means looking at the references used in a paper to find other sources that could be relevant. This helps understand the earlier research that the paper is built on. On the other hand, forward snowballing means looking at more recent papers that have cited the original paper. This helps to see the most recent advancements and discussions in the field [67].

The book "Sustainable Web Design" [11] by Tom Greenwood, was part of the

[1] `https://scholar.google.com/`

[2] `https://ieeexplore.ieee.org/`

curriculum of a web oriented course ("IMT4887 - Specialisation in Web Technology") I attended as part of the master's program at NTNU. It covers multiple aspects of web sustainability, and has been used as a starting point for research snowballing and forming search queries. However, Greenwood seems to focus mainly on white papers and community publications, which posed certain challenges to the research snowballing process, given the often informal and varied nature of these sources.

The following paragraphs outline the specific search queries utilized, the filters applied, and the selection criteria adopted to identify and include appropriate research materials for each of the three sections of Chapter 2. These steps were followed to ensure that the most relevant, recent, and recognized sources in the field were included. This comprehensive and systematic approach to gathering literature ensures a breadth of perspectives and insights, thereby enhancing the depth and quality of the research conducted [65].

Metrics (Section 2.1)

In this rather concise summary of methods to measure the carbon footprint of the web, resources were mainly retrieved through a snowballing process with basis in Tom Greenwood's "Sustainable Web Design" [11]. Greenwood refers to a well-cited paper by Andrae [6], which in turn cites an article by Hintemann et al. Later, Hintemann et al. published another paper [14] addressing the energy consumption of data centers. The article by Belkhir et al. [12] was discovered via forward snowballing, as it cites Andrae's work [6].

On the other hand, the article by Scarlat et al. [13], discussing the carbon intensity of electricity, was directly obtained as the top result of a Google Scholar search using the query "carbon intensity of electricity".

Web Sustainability (Section 2.2)

The literature review of web sustainability in this thesis forms the main part of the background chapter, verifying the research problem and mapping out strategies to solve the problem. The section covers current research on the status of web sustainability (Section 2.2.1), strategies to improve web sustainability (Section 2.2.2), and relevant industry standards and guidelines (Section 2.2.3).

For the first part (Section 2.2.1), articles on data transfer, electricity usage and its carbon intensity are covered, in order to determine how environmentally sustainable the internet is. Several search terms were used, in various combinations: *Energy, consumption, data centers, internet, electricity, use, data, transfer, green IT, sustainable, sustainability*. The search resulted in a very large number (>20,000) of papers, covering various aspects of the ICT sector, some of which focus on its energy consumption and carbon footprint. Filtering and selecting desirable research was demanding, due to the high number of results, where only a few seem to focus on energy consumption and the carbon footprint of the ICT

sector. Therefore, research snowballing was employed with basis in two well cited papers from 2021: Obringer et al.'s "The overlooked environmental footprint of increasing Internet use" [21] and Freitag et al.'s "The real climate and transformative impact of ICT: A critique of estimates, trends, and regulations" [2]. Ultimately, this resulted in 13 resources published by 8 different authors: [2, 6, 12, 13, 15–22, 68].

The second part (Section 2.2.2) is split in two, covering strategies at both management level and development level. In the first section, the search used a mix of terms like *sustainability, sustainable strategies, actions, corporate sustainability, business, key performance indicators*. This search considered papers published since 2015, assuming that the rate of evolution in business strategies might not match the pace of changes seen in web technologies. The search brought up more than 40,000 papers. By choosing papers relevant to the context that were well-cited, and preferably recently published, the list was narrowed down to 15 papers from 15 different authors: [1, 11, 14, 23–34]. The latter section was centered around specific techniques developers can implement. For this purpose, search terms like *progressive web apps, efficiency, development, sustainable, energy performance, runtime* were used. Once again, the search produced a high number of results, over 30,000. To manage this, a similar selection process was applied, until the list was refined down to 12 resources published by 11 unique authors: [7–11, 35–41].

The third part (Section 2.2.3) delves into industry standards and guidelines, mainly referring to those outlined by ISO and W3C. As highlighted in Section 2.2.2, there are many organizations that support sustainability and provide advice. However, given the widespread use of ISO and W3C standards among today's companies, these form the primary reference points. The literature search, a combination of terms including *web, internet, sustainable, guidelines, standards, ISO, W3C* was used. Although the number of relevant findings was limited, two academic publications [42, 45] were considered appropriate for inclusion. An extensive search on the websites of ISO and W3C were conducted, and resulted in four ISO standards [43, 44, 48, 49], along with an article published in the 134th issue of ISOfocus [47], the official ISO magazine[3]. Moreover, the widely recognized Web Content Accessibility Guidelines (WCAG) from W3C is cited [46], along with the the Web Design Community Group and their Web Development committee [50, 51] that are currently working on a set of guidelines.

Project Management Methodologies (Section 2.3)

To start off with, a well formed definition of a project management methodology was needed. As no suitable definition was discovered in academic literature, the web community of practitioners was examined, leading to an informative blog

[3] `https://www.iso.org/isofocus/x/`

post by Adobe that provided clear definitions of project management methodologies and related terminologies [52]. A literature search followed, using keywords like *project, management, methodology, agile, web development, devops, devsecops, bizdevops* in various combinations. The search resulted in more than 20,000 papers. By filtering on papers published after 2019 and prioritizing well-cited works from reputable sources like journals or conference collections, the list was reduced to 10 papers [53–57, 59–62, 64]. Additionally, Riungu-Kalliosaari et al.'s 2016 case study on DevOps [58] was included for its insights into DevOps methodology.

Chapter 4

Method

This chapter outlines the methodologies used in the process of planning and conducting the empirical research. The methods used for data collection are explained, along with the the ethical considerations relevant to this study.

The main data collection method used in this study is focus groups, a form of qualitative research where a group of people are asked about their attitudes towards a product, service, concept, or idea. According to Krueger and Casey [69], they are particularly useful for obtaining several perspectives about the same topic and can encourage participants to make connections and articulate thoughts that might not emerge in one-on-one interviews. The group interaction stimulates a wide range of responses, providing a robust and diverse set of data.

Conducting a focus group study requires careful planning and organization to ensure successful execution of the research. This means maintaining a high level of data integrity, and ensuring that participants feel safe, respected, and valued in the process. The approaches used to prepare and structure the focus groups of this study are outlined in later sections.

In addition to focus groups, semi-structured interviews were conducted to further enrich the set of data. Semi-structured interviews are a qualitative research method where the conversation is guided by predefined topics, but not restricted to them. The method allows for flexibility, encouraging participants to elaborate on their thoughts and experiences. This approach facilitates a balance between maintaining focus on the key topics, while allowing unanticipated insights [70].

Reliability and Validity

By employing predefined methods for data collection, like the ones mentioned above, the reliability of the study is increased [71]. Furthermore, the use of various data collection methods and sourcing data from different people and perspectives is a process known as triangulation [71]. This approach contributes to the validation of the data by confirming that data from different sources point in the same direction.

4.1 Sampling and Recruiting Participants

Focus Groups

The recruitment of participants for the focus groups was performed following a purposeful sampling approach [69], prioritizing professionals who had considerable experience in the field of web development. I approached my employer, Telenor, to explore the possibility of collaboration for this study. Recognizing the value of the discussion on environmentally sustainable web technology, the management team agreed to allow the focus group study to take place during the monthly, hour-long "Coding Chapter" sessions within the department. These sessions, dedicated to software developers, typically serve as a platform for discussing coding techniques, strategies, and challenges, thus proving to be an ideal forum for this study. Gathering developers from various age groups and experiences, these sessions offers a rich diversity of perspectives.

Leaning on the access to the "Coding Chapter" meetings at Telenor, a preliminary presentation of the project was made there a few weeks before the focus group session, with the intention of sparking interest and initiating participant recruitment. Frequent casual conversations were held with colleagues in the department to encourage their participation. This purposeful sampling approach ensured that all participants met the criterion of being field professionals, while preserving diversity in form of gender and age groups. This aligned well with Krueger and Casey's statement that focus groups are "characterized by homogeneity, but with sufficient variation among participants to allow for contrasting opinions" [69]. Both English-speaking and Norwegian-speaking participants were invited to contribute, encouraging further diversity in the participant pool.

A total of 18 participants were recruited for the focus group session, of which 13 were Telenor employees and 5 were external consultants. The group had a balanced gender representation with 10 males and 8 females. Their professional experience was diverse, ranging from less than a year to over three decades. Most of the participants were based in Oslo, Norway.

Semi-structured Interviews

The semi-structured interviews provided an opportunity to engage with individuals possessing distinct perspectives on the topic. Two participants were recruited for these interviews. The first, a member of the "W3C Sustainable Web Design Community Group", was contacted via the community's networking platform, Slack. The second participant, a manager in the technology department at Telenor, was approached through professional channels within the organization. These participants were chosen not only for their unique viewpoints but also for their extensive experience and active roles in the field of web development and sustainable web design.

4.2 Developing Questions and Topics for Discussion

Focus Groups

Considering the limited time frame of the session (approximately one hour) and type of participants, the questions and topics for the focus group were developed. Effective focus group questions and topics are essential for stimulating dynamic conversations and extracting meaningful data [69]. Inspired by the literature review (Chapter 2), open-ended questions were developed to foster in-depth dialogues and exploration of participants' attitudes and experiences.

To ensure the quality and effectiveness of the proposed discussion topics and questions, a preliminary pilot study was carried out. The participants for this study differed from those in the main study to prevent repetition and bias. The pilot study engaged 3 students that are also doing the "Applied Computer Science" Masters Degree at NTNU. They provided insightful feedback and a surprisingly amount of knowledge on the topic of web sustainability, possibly due to the increased focus on sustainability in many courses.

The outcomes of the pilot study were valuable for refining the discussion topics and questions. It was observed that the pilot study participants struggled to get the essence of the discussion topics, as they were too vague. Also, even though the topics were detailed, the lack of questions may have stalled the discussion. Moreover, introducing sustainability already in the second topic seemed to be too soon, given its novelty in the professional field and the risk of a stagnation in the discussion.

Therefore, topics were further clarified and complimented with additional examples and open-ended questions to stimulate efficient and productive conversations. Also, sustainability were saved for the last questions, allowing participants to start off with topics they may have more experience with. Lastly, the topics were made less formal and with shorter sentences to increase readability. The preliminary and the final topics are detailed in Appendix B, while a condensed version is presented below, also highlighting the purpose of each topic:

1. Code optimization and efficient coding techniques
    - Purpose: Identify techniques and practices used to optimize code
2. Tools and frameworks for code/performance optimization
    - Purpose: Identify tools and frameworks used to optimize code
3. Integrating the above towards project management / development life cycle
    - Purpose: Identify if some of the techniques discovered above can be integrated/automated to the development life cycle.
4. How may the actions above lower the carbon footprint of web products?
    - Purpose: Discuss sustainable development/operations techniques, and how to increase awareness on sustainability.

5. General discussion on sustainable web technology
    - Purpose: Identify current knowledge on web sustainability, and whether or not participants would like to learn more. Also discussion of potential obstacles.

Semi-structured Interviews

The semi-structured interviews were organized around a set of predefined topics that guided the conversation in a particular direction. Interview guides with transcriptions are provided in Appendix D. The first conversation, with the member from the "W3C Sustainable Web Design Community Group", was centered around his thoughts on sustainable web technologies, actionable strategies, as well as the evolution and potential future adoption of the W3C guidelines.

The second interview, with the tech-manager from Telenor, was organized around four main topics. The first was to understand the specific strategies employed by Telenor to improve sustainability currently. The second topic focused on how to persuade leaders to prioritize sustainability in the future, given its growing importance. The third part drew parallels between sustainability in technology and the practice of DevSecOps within Telenor. The final topic circled back to sustainability, proposing the concept of "Sustainability Champions" a practice paralleling "Security Champions", which is commonly found in DevSecOps. Other topics, such as corporate responsibility, SDGs, and BizDevOps were also explored during the interview.

The specific topics guiding these conversations and the notes taken during the interviews are provided for further reference in Appendix D of this thesis.

4.3 Running the study

4.3.1 Moderating, Group Roles and Delegation

Following the recommendations by Krueger and Casey [69], the process of running the focus groups were carefully planned. Usually, each focus group has a moderator who is responsible for guiding the discussion, managing time and taking notes. However, this posed a challenge in this study as the three focus groups were conducted simultaneously. Due to this, the decision was made to distribute these roles among the focus groups. The following list detail the structure and responsibilities assigned to these roles within each focus group:

- Facilitator: Directing the conversation, making sure the discussions stayed relevant to the proposed questions and topics, and ensuring that every member had a chance to contribute.
- Time-keeper: Monitoring the time for each discussion, making sure each topic was discussed thoroughly without going off schedule.
- Writer: Take notes and deliver them to the moderator, ensuring that all important insights were captured. As all recruited participants were fluent in

Norwegian, a decision was made to allow for Norwegian note taking, preventing potential language barriers that could slow down the writing process.

Roles were assigned within each group independently, promoting a sense of involvement and commitment in the process. During the planning phase, different methods for role assignment were considered, such as assigning roles based on the alphabetical order of participants' names. However, it was decided that allowing each group to assign roles themselves would create a more relaxed environment and ensure a more efficient execution of the session. In an educational context, the alphabetical approach might be preferred to ensure all participants gain exposure to different roles.

As the primary researcher and moderator of the study, my role was to facilitate and guide the overall process. I frequently switched between groups, offering clarifications and answering any questions that came up. This allowed for effective moderation of discussions, helping to maintain focus and stick to the timeline. Once all groups completed their discussions, I collected their notes and initiated a combined group session. In this session, members from all groups were collectively invited to present their findings and engage in further discussion.

4.3.2 Presenting the Study

As mentioned in Section 4.1, a preliminary presentation of the topic and the current study was made a few weeks prior to the focus group session, with the goal of increasing the number of potential participants.

Additionally, the same presentation was given on the day of the session, in order to refresh participants on the general topic of web sustainability. However, this presentation intentionally did not serve too many specific techniques aimed at improving web sustainability to avoid biasing the discussion.

4.3.3 Technical Execution of the Session

Both the presentations and the focus group session were conducted in a hybrid format, accommodating both remote and on-site participants. Of the total 18 participants, 12 attended remotely, while 6 were present at the office. Hybrid meetings are a common practice at Telenor and thus, did not present significant operational challenges. The conference room used for the session was equipped with digital support to ensure effective communication and participation for all attendees.

Shortly after the presentation, participants were split into three focus groups. The participants on-site formed one group, while the remote participants were split into two groups through digital breakout rooms. As the moderator, I switched between the two digital groups and the physical group to offer assistance.

After the session, the note-taker of each group sent me their discussion notes via work email, which is safely encrypted. However as no personal data was collected this was no problem. These notes served as the primary data for the analysis,

as presented in Chapter 5.

4.4 Research Ethics

In this study, ethical concerns were addressed by implementing specific strategies, ensuring participants' rights. A Data Management Plan (DMP) and an Informed Consent Form were followed, guided by the strategies suggested by Corbin and Strauss [70].

Data Management Plan (DMP)

As the desired data were related to experiences and opinions rather than demographic and sensitive personal data, it was decided that notifying the project to Sikt[1], which is a legal requirement for projects which processes personal data, was not necessary.

However, data management is still important [70], therefore a DMP was developed through Sikt's platform, and followed during data collection and storage. The DMP outlines the procedures for data collection, storage, and archiving, as well as indicating relevant ethical guidelines. This ensures data integrity and compliance with ethical standards.

For each of the data collection methods applied in this study, a classification were made whether or not data about people were collected. For the focus groups and the semi-structured interviews, personal data such as the organizations associated with each participant and their respective roles were collected. However, no identifiable data such as names or recordings were gathered.

As of ethical guidelines, three categories were selected relevant for the project: "General guidelines for research ethics"[2], "Science and Technology"[3], and "Internet Research"[4].

The complete DMP is provided in Appendix C.

Informed Consent Form

Further ensuring the ethical conduct of this research, an informed consent form were created [70] (**provided in the Appendix C**). Participants received an informed consent form to sign prior to taking part of the study. This form detailed the study's purpose, outlined how participants' data would be used and protected, and clarified participants' rights. Also, it underlined that participation was voluntary and that participants could withdraw from the study at any time without consequences.

[1] Norwegian Agency for Shared Services in Education and Research
[2] National Research Ethics Committees: General guidelines
[3] National Research Ethics Committees: Guidelines for Research Ethics in Science and Technology
[4] National Research Ethics Committees: A Guide to Internet Research Ethics

Traditionally, informed consent forms requires physical signatures, adding an extra layer of work for both participants and researchers before the study can begin. To streamline this process, this study opted for a digital consent strategy, requiring only a straightforward digital action from participants. Leveraging Telenor's internal communication channels, participants were asked to respond to a post containing the informed consent form while logged into their work accounts, thereby verifying their identity. This method not only secured participant consent efficiently but also ensured that no personal data were collected, thus respecting and upholding ethical standards throughout the research process.

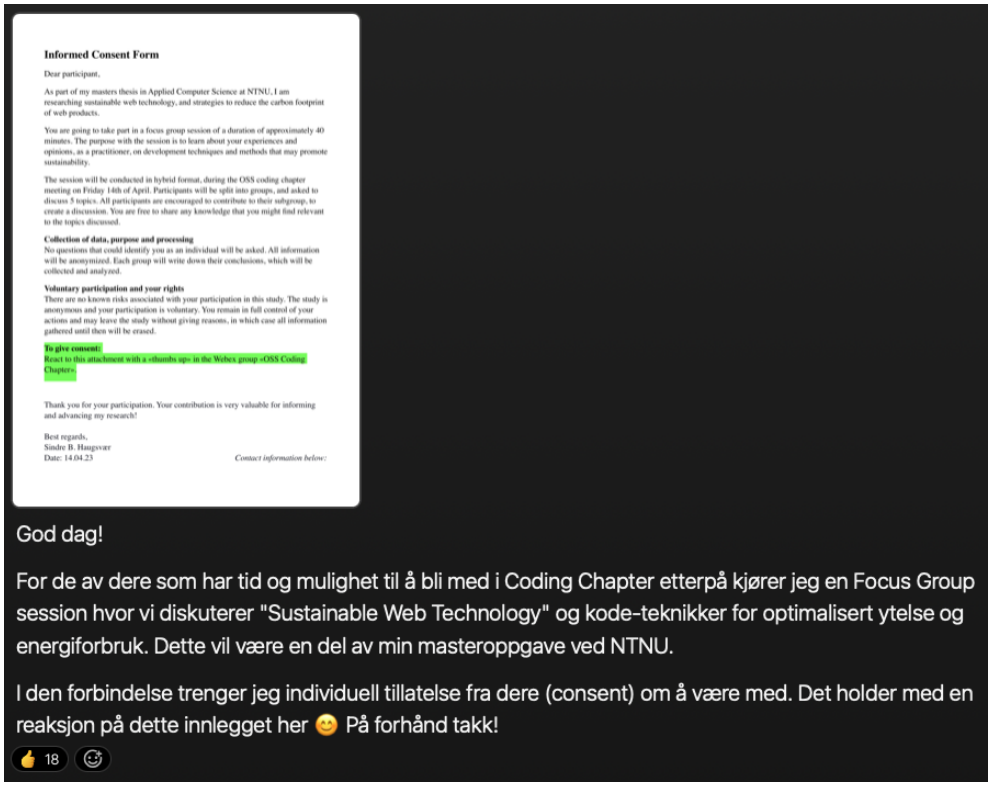

Figure 4.1: Screenshot from an internal communication channel, showcasing the number of "likes", or consent.

Chapter 5

Results

In this chapter, the second research question is answered through the process of analysing data that accumulates into a novel project management methodology aiming to reduce the carbon footprint of web products. The proposed methodology is grounded in the collected data, utilizing the grounded theory approach as described in Chapter 4. The concrete actions provided with the methodology mirrors the perspectives and insights of the participants of the focus groups and the semi-structured interviews, as well as findings in existing research, as detailed in Chapter 7.

Key documents are provided in the appendix, and referenced throughout this chapter.

5.1 Data Analysis through Grounded theory

Grounded theory, first introduced by Glaser and Strauss in 1967 [72], is a research methodology for data analysis, interpretation and presentation [71]. It emphasizes the development of theory through a systematic and iterative process of coding, data gathering and analysis. As explained by Corbin and Strauss [70], data collection and analysis inform and refine each other, ultimately enabling a comprehensive understanding of the research context and emergent phenomena.

This study utilized data from the focus groups as the foundation for analysis, which has been proven to enrich the research process [69]. As part of the iterative process, additional data is incorporated, sourced from the conducted literature review (Chapter 2), ongoing work by the "W3C Sustainability Community Group" [50], as well as two semi-structured interviews. This approach enhances the data set and strengthens its validity, as mentioned in Section 4.

5.1.1 Interpretation and Rewriting

Before initiating the coding process, the raw data went through iterations of formatting, interpreting, rewriting, and translating. The keywords retrieved from the focus groups were somewhat unclear and short in form, due to the limited time

during the focus group session. Both the raw data (in structured form), and the translated and rewritten version are available in the appendix (Appendix D).

To increase the readability of the data in this phase, terms and names of tools and techniques were described and put in context, and explanatory URL's were added.

5.1.2 Open Coding

At this stage, the data were classified into categories representing various ideas or concepts. Each category were assigned a unique code and color, to capture their essence and facilitate for constant comparison [73]. Additionally, to further refine the analysis, a "magnitude coding" approach was implemented as per the guidance of Preece et al. [71]. This entailed counting the frequency of comments within each category, providing an additional layer of insight into the data.

It was discovered that the data from the first two discussion topics had significant similarities, as techniques often imply using different tools and frameworks. Therefore, most of the data gathered from topic 1 and 2 were merged into a category "C" for "Coding Techniques". Furthermore, many comments were related to application deployment, forming a new category, "D". A high number of comments were related to awareness and knowledge, discussing various ways to increase the sustainability-awareness and educate professionals in the industry of web development. Lastly, the remaining comments were put in a general category, "G". Figure 5.1 displays the categories and codes that emerged from the first set of data, gathered from the focus groups, and Figure 5.2 demonstrates the process of open coding. A total of 66 comments were collected and distributed throughout the categories (available in Appendix D).

Categories:	Codes:	Number of comments
Coding Techniques / Tools / Frameworks	C	31
Deployment / Integration / Automation	D	8
Awareness	A	6
General Thoughts / Other Ideas	G	21
	Sum:	66

Figure 5.1: The categories and codes that emerged through open coding

5.1.3 Axial Coding

Building on the open coding stage, axial coding is an intermediate process aimed at reorganizing the previously created codes into meaningful categories and sub-

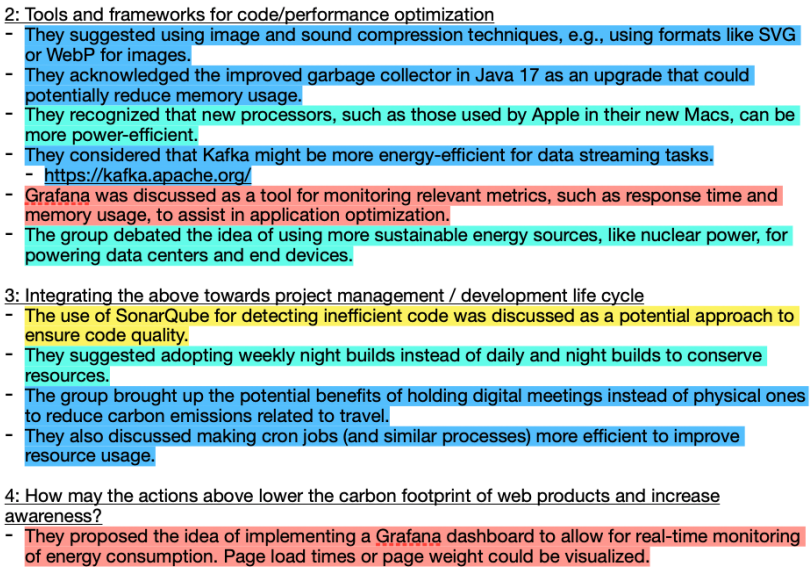

Figure 5.2: Screenshot from the open coding process

categories. This process plays a significant role in constructing a more systematic and detailed understanding of the data, and allows us to discover potential patterns and connections through constant comparison [73].

This step was conducted with the goal of the study in mind, as the evolving theory needed to align with the research questions of the study. Emphasis was put on comments that may be related to the footprint of the end products of the web, instead of the embedded emissions derived from development and operations processes like office equipment and transportation. Therefore, a number of comments were identified as irrelevant and excluded from further analysis.

The analysis in this phase led to the identification of several new categories. A few comments previously coded as "G" addressed challenges that could be brought to the attention of managers, proposing potential changes. Thus, a new category, "M", was defined to capture these manager-oriented discussions.

In addition, some comments were related to planning and design. As a result, another category, "P", was created to include these discussions.

The largest category from the open coding phase, "C", was broken down into more nuanced subcategories, covering "code review/quality", "caching", "backend", and "frontend".

The total number of comments were reduced to 55, enhancing their relevance to the research goal. The resulting categories and subcategories that emerged from the axial coding process can be seen in Figure 5.3 (full version in Appendix D).

Categories:	Codes:	Number of comments
Code Review / Code Quality	C1	6
Caching	C2	4
Backend	C3	11
Frontend	C4	8
Deployment / Integration / Automation	D	10
Awareness	A	6
General Thoughts / Other Ideas	G	3
Planning / Design	P	3
To Management	M	4
	Sum:	55

Figure 5.3: The refined categories and codes after axial coding

5.1.4 Additional Data Collection

To enrich the available data and further improve the emerging theory, additional data was collected during the process, as described in Chapter 4. This included the key findings from the literature review (Chapter 2), the ongoing work by the "W3C Sustainability Community Group" [50], and the two semi-structured interviews introduced earlier (Appendix D).

58 new comments were added to the data set, increasing the total amount of comments to 113 comments. The addition and analysis of data resulted in some rearrangement, which led to the formation of four major categories. The order of the categories were altered, reflecting the order of the development life cycle of web products, as illustrated in Figure 5.4. Figure 5.5 presents the key actions formed from the available data, utilizing a "process coding" approach inspired by Preece et al [71]. Then, the frequency of comments related to each action are listed to compare the relevance of each action.

Categories:	Codes:	Number of comments
Planning / Design	P	9
Coding (General, Frontend, Backend)	C	60
Operation	O	18
Management/Business/Strategy (Awareness, Challenges and strategies, Current knowledge)	M	26
Sum:		113

Figure 5.4: The refined categories after adding and reorganizing the data

Codes:	Core Categories and Key Actions:	Comments related to action:
P	**Planning / Design:**	
	- Design for data efficiency (navigation, asset minimizing)	4
	- Plan for sustainable dev and ops (assign sustainability representative, estimate environmental impact, set sustainability budget)	3
	- Design for energy-saving on end devices (e.g dark mode)	2
C	**Coding techniques / tools / frameworks (General, Frontend, Backend)**	
	- Minify assets, HTML, CSS, JS	7
	- Use code inspection/review tools, to optimize code quality and efficiency	6
	- Optimize browser caching / caching techniques	6
	- Efficient database queries	6
	- Encourage to follow W3C Sustainability Guidelines	
O	**Operation**	
	- Use automated quality control tools	8
	- Limit number of deployment-builds	5
	- Choose sustainable partners / hosting providers	4
M	**Management/Business/Strategy**	
	- Build knowledge and culture. Prioritize education on sustainable practices	8
	- Corporate focus on sustainability. Especially in large companies. Driving the change. Others will follow.	8
	- Visualize status / progress on metrics (e.g page load times / page weight) and goals	5

Figure 5.5: The key actions linked to the core categories

The majority of new comments were related to specific coding techniques, aligning well with the ideas that were discussed during the focus groups. With the added data points to the "C" category, some specific actions were frequently mentioned: "asset compression", "usage of code inspection/review tools", "cache optimization", and "efficient database queries".

On the other hand, the two semi-structured interviews provided mostly ideas and strategies related to the "O" and "M" categories. Both of the interview participants highlighted the importance of increasing the focus on sustainability.

The member of the W3C Community Group contributed with some additional insight into their initiative. For instance, he gladly highlighted that lots of individual professionals are involved in the initiative, as well as some industry leading companies like Microsoft, Salesforce, Mozilla and Google. He also brought up a concern related to adopting current standards, stating that "ISO standards are behind a paywall, which strides against the open-source/open access/open learning environment fundamentals of the web. These cost barriers may hinder smaller

businesses and individuals in following these". This underscores the importance of the work they do, by working towards delivering an open access web standard.

The Telenor manager expressed a desire to strengthen the knowledge in the area of sustainable web technologies, and "stay at the forefront of advancements in this field". Additionally, the current DevOps practices in Telenor were discussed. It was revealed that a variant of DevSecOps, with emphasis on business, is prevalent within the company. They practice so called "Security Champions", meaning dedicated roles to promote and ensure security across teams.

This insight underscored potential obstacles in the path of sustainable web technology adoption, further shaping the analysis.

5.1.5 Selective Coding and Theory Construction

As the final phase of the grounded theory approach, this step entailed identifying a core category that connects all the previously defined codes, leading to the construction of a theory. Forming the backbone of the emerging methodology, this coding step integrates and compares current methodologies to the concrete actions identified so far (Appendix D).

The four core categories that emerged through the previous steps aligned well with the DevOps methodology presented in Section 2.3, but enriched with an additional management/business aspect such as in BizDevOps. There was also a correlation towards the committees that form the "W3C Sustainable Web Design Community Group", responsible for developing guidelines for each of their specialist areas:

- UX Design
- Web Development
- Hosting, Infrastructure, Systems
- Analytics, Measurement, Reporting
- Business Strategy, Product Management

Therefore, a link was made between the phases of BizDevOps, the core categories of the study, and the W3C committees. The committee working on analytics, measurement, and reporting, however, was excluded as they have not yet published their draft guidelines.

This observation, visualized in Figure 5.6, formed the core category selected for the study: A Sustainability-Enhanced BizDevOps Methodology. Drawing parallels between these phases, categories and committees, formed a novel methodology that connects various sustainability aspects to the project management methodology BizDevOps. It emphasizes a holistic approach that unites business, development, operations, and sustainability considerations, thereby offering a concrete pathway to ensure more sustainable web products.

Sustainability-Enhanced BizDevOps		
The phases of BizDevOps:	**Core Categories of the Study**	**W3C Sustainable Web Design Committees:**
Idea	Management/Business/ Strategy	Business Strategy, Product Management
UI/UX Design	Planning / Design	UX Design
Plan		Business Strategy, Product Management
Code	Coding (General, Frontend, Backend)	Web Development
Build		
Test		
Release		
Deploy	Operation	Hosting, Infrastructure, Systems
Operate		
Monitor		
Feedback	Management/Business/ Strategy	Business Strategy, Product Management
Analyze		

Figure 5.6: Through selective coding, the BizDevOps methodology has been compared and integrated with the core categories of the study and to the W3C committees currently working on publishing guidelines in respective categories

Chapter 6

Discussion

6.1 The proposed methodology: Sustainable BizDevOps

Before presenting the details of the novel methodology, the key actions identified during the data analysis were matched with the phases of the development life cycle affiliated with BizDevOps (Figure 6.1). This helped to further shape the proposal. Most of these actions could naturally be assigned to either business- (Biz), development- (Dev), or operations (Ops) teams. However, some actions were more overarching, pointing towards all stakeholders. To include these actions, a new category, named "Sustainability", has been added.

Figure 6.2 illustrates the proposed methodology, by encapsulating the BizDevOps methodology with a layer of unified sustainable focus. The following sections present the concrete measures that can be applied to the respective teams. These measures are directly linked to the results and insights derived from the research, establishing a clear connection between the study's outcomes and the recommended actions for each team.

6.1.1 Sustainability

While not directed towards a specific team, these specifications and guidelines are more general. They put emphasis on building knowledge and creating a culture for sustainability, which in turn may lead to increased awareness and more sustainable processes throughout the entire development life cycle. This aligns well with the findings of both the focus groups and the interviews, as a high number of comments were related to awareness. During the selective coding process (Section 5.1.5), the awareness category was merged with the "M" (management) category, which in this proposal is altered to "Biz" (business). However, in line with the findings of the literature review, it is important to note that culture and awareness are cultivated through various factors across organizations rather than being solely delegated to a smaller group [59, 62]. Therefore, this category represents broader actions that should be adopted by various teams throughout organizations.

	The phases of BizDevOps:	Key Actions: Comments related to action:	
Sus		- Build knowledge and culture. Prioritize education on sustainable practices	8
		- Corporate focus on sustainability. Especially in large companies. Driving the change. Others will follow.	8
Biz	Feedback	- Visualize status / progress on metrics (e.g page load times / page weight) and goals	5
	Analyze		
	Idea		
	UI/UX Design	- Design for data efficiency (navigation, asset minimizing)	4
		- Design for energy-saving on end devices (e.g dark mode)	2
	Plan	- Plan for sustainable dev and ops (assign sustainability representative, estimate environmental impact, set sustainability budget)	3
		- Choose sustainable partners / hosting providers	4
Dev	Code	- Minify assets, HTML, CSS, JS	7
		- Optimize browser caching / caching techniques	6
		- Efficient database queries	6
		- Encourage to follow W3C Sustainability Guidelines	1
	Build		
	Test	- Use code inspection/review tools, to optimize code quality and efficiency	6
	Release		
Ops	Deploy	- Limit number of deployment-builds	5
	Operate	- Use automated quality control tools	8
	Monitor		

Figure 6.1: Key actions matched with BizDevOps

Corporate Focus on Sustainability

Incorporating sustainability into the broader corporate focus is key to spread awareness throughout organizations. This may be done by setting sustainability goals that align with the SDGs, and tracking progress through KPIs. However, it is vital to clearly communicate these visions and goals to all teams that are involved in development and operations of web products.

The internet is growing rapidly, along with its share of the global carbon footprint. Therefore, it is likely that the importance of web sustainability will gradually increase in the years to come. Organizations that prioritize web sustainability may position themselves at the forefront of this shift. This can result in enhanced credibility and potential sales growth, as sustainable solutions become increasingly desirable and often a requirement for customers. Larger companies that prioritize education and the formation of a culture emphasizing sustainability are likely to

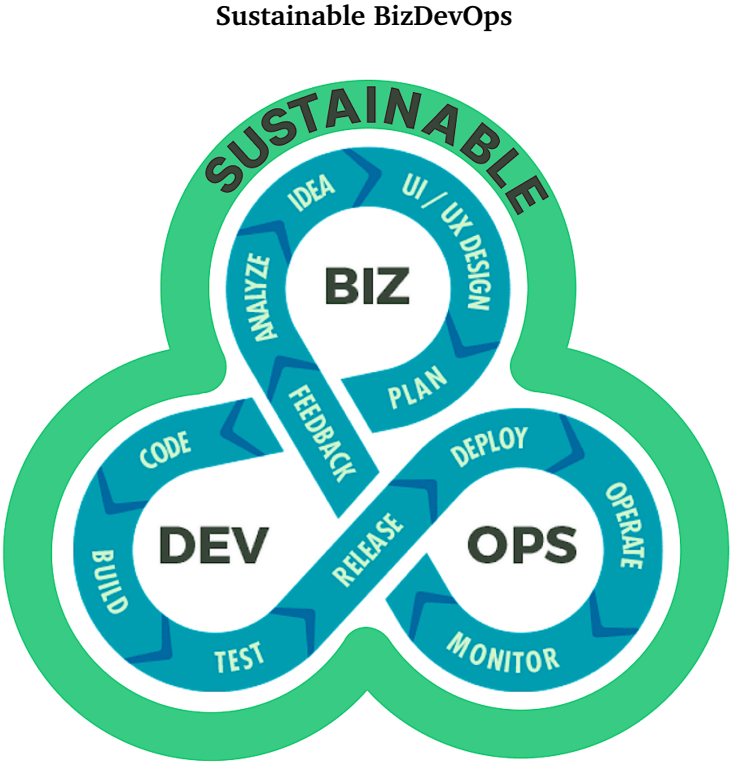

Figure 6.2: Illustration of the proposed Sustainable BizDevOps methodology.

set a trend for others to follow.

Knowledge

Many companies, like Telenor, already have sustainability as an overarching requirement and goal throughout departments. However, the findings from the focus groups and interviews highlight a significant lack of knowledge on web sustainability among professionals (Section 5.1.2). As suggested during the focus groups session, incorporating sustainable best practices into "Show & Tell" presentations, seminars and conferences will equip professionals with the necessary knowledge, and may inspire a change (Appendix D).

Culture

Along with increasing the knowledge base by providing concrete guidelines, establishing a culture for sustainable development is the next step. Doing so involves commitment and desire at various levels, from management to individual developers. With commitment comes willingness to implement actions, such as the ones presented below, spread across the various teams of the BizDevOps approach. Often it's just a matter of getting the ball rolling, by initiating measures

somewhere. This is supported by the interview with the Telenor manager, who states that "culture may spread throughout the organization" (Appendix D).

6.1.2 Biz - Business

The decision to base the proposed methodology on BizDevOps rather than the standard DevOps or DevSecOps emerged from insights gathered during the interview with the manager at Telenor (Appendix D), as described in Section 5.1.4. The manager suggested that reducing the gap between business and DevOps teams could lead to a smoother adjustment of requirements and improve communication. This idea matches with the findings of recent research, proposing that BizDevOps can foster a stronger sense of ownership among technology workers and enhance communication across teams [62, 63]. If employees feel a deeper connection to their work and maintain efficient communication across teams, it may set the stage for a successful integration of sustainability practices into their routines.

Business teams are involved with several phases of the BizDevOps life cycle. This study identified sustainability actions related to three of them:

Feedback

Feedback mechanisms are key in elevating awareness and driving improvements in sustainable practices. As suggested during the focus groups, tools such as Grafana[1] may be useful for this purpose (Appendix D). It allows for real-time tracking and visualization of metrics like page loading times and page weight. By monitoring these metrics, sustainability goals are made more concrete, which in turn can make them easier to achieve [11].

UI/UX Design

Some of the key actions that emerged during the data analysis are related to designing and planning for data efficiency and energy efficient solutions (Figure 5.5). Design choices can have a direct effect on data usage and energy consumption. By focusing on efficient navigation, the number of required clicks by users to arrive at the desired end point may be reduced, resulting in less data transmitted and potentially higher user satisfaction. Likewise, recommending designs that encourage asset size reduction can enhance the energy efficiency of products. For instance, opting for vector graphics or WebP image formats instead of JPEG can significantly reduce file sizes [11, 35]. Additionally, offering a dark-mode feature can decrease the energy consumption of end devices. Keeping these considerations in mind throughout an agile and iterative design process can lead to the development of more sustainable web products.

[1] `https://grafana.com/`

Plan

Concrete actions related to incorporating sustainability into the planning stage were revealed in Chapter 5. Figure 5.5 briefly introduces some concepts that are further explained here.

A dedicated individual or team may be assigned to be sustainability representatives, leading the way for sustainable development and operations. These roles mirrors the "Security Champion" role in DevSecOps, which is proved to be efficient [59]. These individuals can be tasked with assessing the potential environmental impact of proposed solutions. This could include establishing a "sustainability budget", referring to the process of estimating and establishing a target for the environmental impact of a product. It involves setting and pursuing specific goals to reduce footprint [11]. Lastly, choosing to work with partners and hosting providers who also have a focus on sustainability can ensure that sustainable practices are maintained throughout the project.

6.1.3 Dev - Development

The most concrete actions discovered during the data analysis were related to the development processes (Figure 5.5). The study suggests considering the following recommended actions:

Code

In transitioning towards more sustainable web products, reducing the amount of data transmitted is crucial. Here are specific approaches to achieve this:

- Minifying assets, such as HTML, CSS, and JavaScript files, reduces the overall project size, resulting in minimized data transfer.
- Implementing efficient browser caching techniques can optimize data transmission by reducing the amount of data that needs to be transferred.
- Optimizing database queries to retrieve only necessary data can contribute to minimizing data transfer.

The actions above are supported by findings in both the literature review, focus groups, interviews and the preliminary guidelines from the W3C Sustainable Web Design Community Group. According to the interview with the W3C member (available in Appendix D), the community group is expected to publish their guidelines as a "non-standardized report" during the fall of 2023. Further, the member states that "in the future, one goal is to develop it into a open access web standard, equivalent to the Web Content Accessibility Guidelines (WCAG)[2]". With this in mind, these upcoming guidelines may be serve as a solid baseline for sustainable web development.

[2] `https://www.w3.org/WAI/standards-guidelines/wcag/`

Test

To enhance code quality and efficiency, development teams can utilize code inspection and review tools, such as linters and formatters. Multiple comments gathered during the focus group session (Appendix D) mentioned SonarLint[3] as a useful tool to provide continuous code quality inspection and automated code review capabilities, identifying potential code inefficiencies. Tools like this help maintain clean and efficient code. By employing thorough testing and inspection prior to code release, developers can spot and correct potential problems, thereby improving overall code quality and performance.

6.1.4 Ops - Operations

Lastly, for operations teams, the study discovered two key actions supported by many comments, as seen in Figure 5.5:

Deploy

Managing the deployment process may contribute to conserving computational resources and energy. Many software teams operate with a Continuous Integration/Continuous Delivery (CI/CD) pipeline, meaning that the deployment process is automated. While this may save developers and operators for work, and reduce time to market (TTM), frequent deployment builds can put considerable stress on the network. Therefore, balancing the benefits of rapid deployment with the need for resource conservation can play a part in achieving a more sustainable web product operations process.

Operate

In the operation phase of the BizDevOps cycle, monitoring performance and key sustainability metrics, such as page weight and loading times, can provide important insights. This data allows operators to create detailed reports, which in turn can be reviewed in the next iteration of the development cycle, reinforcing the iterative nature of the BizDevOps approach.

Several tools can aid in this process. Google Lighthouse[4] and WebPageTest[5] are useful for testing and generating in-depth reports on web application performance. Notably, WebPageTest recently added a feature to measure the carbon footprint of web applications, and offering suggestions for improvement. The Green Web Foundation[6] offers a valuable tool that verifies whether web applications are hosted by providers committed to operating on renewable energy sources.

[3] `https://www.sonarsource.com/products/sonarlint/`
[4] `https://developer.chrome.com/docs/lighthouse/overview/`
[5] `https://www.webpagetest.org/`
[6] `https://www.thegreenwebfoundation.org/`

6.2 Implications

The "Sustainable BizDevOps" methodology proposed in this study has implications for both academia and the industry, particularly when considering the current absence of comprehensive guidelines for the environmentally sustainable development and operation of web products (Chapter 2).

While each proposed guideline or action may represent small changes in the carbon footprint of the web, their combined effect has the potential make a difference. However, it is essential to note that the adoption of the methodology may require education, which come at a cost, meaning that it will have to be prioritized by management. At this time, there are no requirements specific to the environmental sustainability of web products, set by the industry or governments. Consequently, the motivation to adopt these guidelines needs to come from the organizations themselves, either driven by their own sustainability agendas, public pressure, or recognition of potential future regulatory requirements.

The ongoing development of sustainable web design guidelines by W3C could encourage a growing interest in sustainable web development. As a result, organizations that proactively adopt the Sustainable BizDevOps methodology might find themselves better prepared when these broader industry guidelines are put into place. This forward-thinking approach may not only result in environmental advantages but also provide a competitive advantage in a business world increasingly influenced by sustainability efforts.

Moreover, even if not directly adopted, the findings of this thesis can serve to inspire and increase awareness about sustainability in web development. The proposed methodology can provide a guiding example, helping to prompt change in sustainable practices within the industry and increase overall awareness about the environmental impacts of web development.

6.3 Limitations

sample size limitations: 18 participants in focus groups + 2 participants in semi-structured interviews.

data collection limitations: for the focus group experiment, I was assigned one hour during work hours at Telenor. In order to improve the dataset, it could be an advantage to conduct longer sessions. However, expecting the company to allocate more time in a hectic weekday is unreasonable.

Sampling bias may be a limitation. As I did all the sampling myself. The two interviews were conducted with people generally positive and ambitious about sustainability within web technology. The outcome may have been altered if the participants had other views on it.

At last, the proposed methodology could not be tested by a functioning development team within the scope of a Master's thesis, so as a future experiment - Sustainable BizDevOps may be tested and measured using the metrics mentioned

in Section 2.1, and evaluated accordingly and by using digital tools like the ones presented in Section 2.2.2.

Chapter 7

Conclusion

Through an extensive literature review process, this study has confirmed the fact that the ICT sector and the internet contribute to significant global carbon emissions. This is part of a growing concern as the demand for web-based services and digital products is increasing, further expanding the carbon footprint of the sector. Strategies to reduce the carbon footprint of web products has been investigated. Despite the heightened awareness around environmental sustainability, there exists a gap in practical and comprehensive guidelines that specifically address the reduction of carbon footprint in the development and operation of web products.

The main contribution of this thesis is the proposal of a novel methodology, Sustainable BizDevOps, formulated in an attempt to fill this gap. The methodology is grounded in the principles of widely adopted DevOps and BizDevOps methodologies, and developed through an iterative process of collecting and analysing data from focus groups, semi-structured interviews, the literature review, and insights from the W3C Sustainable Web Design Community Group. The methodology recommends concrete and sustainable actions through various phases of the development life cycle of web products.

The ultimate success of this methodology, however, is not guaranteed. It largely depends on the willingness of organizations to prioritize and invest in sustainable practices. As of now, there is a lack of clear industry or governmental regulations driving such a shift. However, as proven in the interview with the Telenor manager, corporate environmental responsibility is already a big priority in Telenor, and probably also in similar corporations. Likewise, the movement in the community, such as the initiatives by W3C proves that there is motivation for change. The upcoming W3C sustainability guidelines is likely to be important in the years to come.

Moving forward, the Sustainable BizDevOps methodology, with its comprehensive coverage of all phases of the software development life cycle, presents a holistic approach to integrating sustainability in web development. By addressing each stage, from planning to deployment and maintenance, it aims to trigger meaningful changes in current practices. The broad scope of the methodology encourages organizations to weave sustainability into their entire process, rather

than limiting it to specific aspects.

Future Work

While the methods employed in this study provided a solid foundation for structuring and analysing the data, there is room for further iterations of the grounded theory process. By revisiting the data analysis phase and refining the existing methodology, future research could yield a more detailed and robust version of the Sustainable BizDevOps methodology, further contributing to the body of knowledge on sustainable web development.

Looking forward, future research could also benefit from expanding the pool of participants for both focus groups and interviews. By incorporating a larger and more diverse sample, including professionals from various organizations and positions within the field of web development, more nuanced insights and detailed data can be expected to be collected.

Assessing the overall effectiveness of implementing Sustainable BizDevOps and comparing its footprint to a conventional methodology would be interesting. However, this could be challenging due to complexities associated with measuring the strain on the telecommunication network, accurately incorporating all energy sources into the calculation, and accounting for differences in problem-solving approaches among individual practitioners. Despite these potential challenges, such a study would be a significant step in evaluating and refining the Sustainable BizDevOps methodology.

Lastly, security is an essential aspect of any web development process, and may be put in the context of other sustainability aspects. While it was beyond the scope of this study, future research could focus on integrating aspects of security into the Sustainable BizDevOps methodology. As sustainability becomes a more integral part of web development processes, exploring the intersection of security and sustainability could yield new insights and enhancements. This could lead to the evolution of a more comprehensive methodology that balances security and sustainability needs in web development.

This study breaks new ground, but the concepts and advice it offers have strong support from the web development community. The journey ahead involves organizations, web developers, academic researchers, and policy makers, all playing their part in embedding sustainability into web development practices. The challenge lies in shifting from viewing sustainability as an optional addition, to treating it as an integral part of the web development process.

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Appendix A

Masters Agreement

Masteravtale/hovedoppgaveavtale

Sist oppdatert 11. november 2020

Fakultet	**Fakultet for informasjonsteknologi og elektroteknikk**
Institutt	**Institutt for datateknologi og informatikk**
Studieprogram	**MACS**
Emnekode	**MACS490**

Studenten

Etternavn, fornavn	**Haugsvær, Sindre Bjerkestrand**
Fødselsdato	**05.03.1994**
E-postadresse ved NTNU	**sindrbh@stud.ntnu.no**

Tilknyttede ressurser

Veileder	**Johanna Johansen**
Eventuelle medveiledere	**Nina Tvenge**
Eventuelle medstudenter	

Oppgaven

Oppstartsdato	**02.01.2023**
Leveringsfrist	**01.06.2023**
Oppgavens arbeidstittel	**"From DevOps to GreenOps: A Sustainable Project Management Approach for Web Development" (May be revised before thesis submission)**
Problembeskrivelse	**The carbon footprint of the web and its many web products is significant, and contribute to a considerable amount of CO2-emissions due to high energy consumption. This project investigates current research and industry practices, and proposes a methodology that can be employed by web development teams to ensure reduced carbon footprint of web products.**

Risikovurdering og datahåndtering

Skal det gjennomføres risikovurdering? **Dersom «ja», har det blitt gjennomført?**	**Nei** **Nei**
Skal det søkes om godkjenninger? (REK*, NSD)**	**Nei**
Skal det skrives en konfidensialitetsavtale i forbindelse med oppgaven? **Hvis «ja», har det blitt gjort?**	**Nei** **Nei**

* Regionale komiteer for medisinsk og helsefaglig forskningsetikk (https://rekportalen.no)

** Norsk senter for forskningsdata (https://nsd.no/)

Eventuelle emner som skal inngå i mastergraden

Retningslinjer - rettigheter og plikter

Formål

Avtale om veiledning av masteroppgaven/hovedoppgaven er en samarbeidsavtale mellom student, veileder og institutt. Avtalen regulerer veiledningsforholdet, omfang, art og ansvarsfordeling.

Studieprogrammet og arbeidet med oppgaven er regulert av Universitets- og høgskoleloven, NTNUs studieforskrift og gjeldende studieplan. Informasjon om emnet, som oppgaven inngår i, finner du i emnebeskrivelsen.

Veiledning

Studenten har ansvar for å

- Avtale veiledningstimer med veileder innenfor rammene master-/hovedoppgaveavtalen gir.
- Utarbeide framdriftsplan for arbeidet i samråd med veileder, inkludert veiledningsplan.
- Holde oversikt over antall brukte veiledningstimer sammen med veileder.
- Gi veileder nødvendig skriftlig materiale i rimelig tid før veiledning.
- Holde instituttet og veileder orientert om eventuelle forsinkelser.
- Inkludere eventuell(e) medstudent(er) i avtalen.

Veileder har ansvar for å

- Avklare forventninger om veiledningsforholdet.
- Sørge for at det søkes om eventuelle nødvendige godkjenninger (etikk, personvernhensyn).
- Gi råd om formulering og avgrensning av tema og problemstilling, slik at arbeidet er gjennomførbart innenfor normert eller avtalt studietid.
- Drøfte og vurdere hypoteser og metoder.
- Gi råd vedrørende faglitteratur, kildemateriale, datagrunnlag, dokumentasjon og eventuelt ressursbehov.
- Drøfte framstillingsform (eksempelvis disposisjon og språklig form).
- Drøfte resultater og tolkninger.
- Holde seg orientert om progresjonen i studentens arbeid i henhold til avtalt tids- og arbeidsplan, og følge opp studenten ved behov.
- Sammen med studenten holde oversikt over antall brukte veiledningstimer.

Instituttet har ansvar for å

- Sørge for at avtalen blir inngått.
- Finne og oppnevne veileder(e).
- Inngå avtale med annet institutt/ fakultet/institusjon dersom det er oppnevnt ekstern medveileder.
- I samarbeid med veileder holde oversikt over studentens framdrift, antall brukte veiledningstimer, og følge opp dersom studenten er forsinket i henhold til avtalen.
- Oppnevne ny veileder og sørge for inngåelse av ny avtale dersom:
    - Veileder blir fraværende på grunn av eksempelvis forskningstermin, sykdom, eller reiser.
    - Student eller veileder ber om å få avslutte avtalen fordi en av partene ikke følger den.
    - Andre forhold gjør at partene finner det hensiktsmessig med ny veileder.
- Gi studenten beskjed når veiledningsforholdet opphører.
- Informere veileder(e) om ansvaret for å ivareta forskningsetiske forhold, personvernhensyn og veiledningsetiske forhold.
- Ønsker student, eller veileder, å bli løst fra avtalen må det søkes til instituttet. Instituttet må i et slikt tilfelle oppnevne ny veileder.

Avtaleskjemaet skal godkjennes når retningslinjene er gjennomgått.

Godkjent av

Sindre Bjerkestrand Haugsvær
Student

14.03.2023
Digitalt godkjent

Johanna Johansen
Veileder

14.03.2023
Digitalt godkjent

Hilde Bakke
Institutt

22.03.2023
Digitalt godkjent

Master`s Agreement / Main Thesis Agreement

Faculty	**Faculty of Information Technology and Electrical Engineering**
Institute	**Department of Computer Science**
Programme Code	**MACS**
Course Code	**MACS490**

Personal Information

Surname, First Name	**Haugsvær, Sindre Bjerkestrand**
Date of Birth	**05.03.1994**
Email	**sindrbh@stud.ntnu.no**

Supervision and Co-authors

Supervisor	**Johanna Johansen**
Co-supervisors (if applicable)	**Nina Tvenge**
Co-authors (if applicable)	

The Master`s thesis

Starting Date	**02.01.2023**
Submission Deadline	**01.06.2023**
Thesis Working Title	**"From DevOps to GreenOps: A Sustainable Project Management Approach for Web Development" (May be revised before thesis submission)**
Problem Description	**The carbon footprint of the web and its many web products is significant, and contribute to a considerable amount of CO2-emissions due to high energy consumption. This project investigates current research and industry practices, and proposes a methodology that can be employed by web development teams to ensure reduced carbon footprint of web products.**

Risk Assessment and Data Management	
Will you conduct a Risk Assessment? **If "Yes", Is the Risk Assessment Conducted?**	**No** **No**
Will you Apply for Data Management? **(REK*, NSD**)**	**No**
Will You Write a Confidentiality Agreement? **If "Yes", Is the Confidentiality Agreement Conducted?**	**No** **No**

* REK -- https://rekportalen.no/

** Norwegian Centre for Research Data (https://nsd.no/nsd/english/index.html)

Topics to be included in the Master`s Degree (if applicable)

Guidelines – Rights and Obligations

Purpose

The Master's Agreement/ Main Thesis Agreement is an agreement between the student, supervisor, and department. The agreement regulates supervision conditions, scope, nature, and responsibilities concerning the thesis.

The study programme and the thesis are regulated by the Universities and University Colleges Act, NTNU's study regulations, and the current curriculum for the study programme.

Supervision

The student is responsible for

- Arranging the supervision within the framework provided by the agreement.
- Preparing a plan of progress in cooperation with the supervisor, including a supervision schedule.
- Keeping track of the counselling hours.
- Providing the supervisor with the necessary written material in a timely manner before the supervision.
- Keeping the institute and supervisor informed of any delays.
- Adding fellow student(s) to the agreement, if the thesis has more than one author.

The supervisor is responsible for

- Clarifying expectations and how the supervision should take place.
- Ensuring that any necessary approvals are acquired (REC, ethics, privacy).
- Advising on the demarcation of the topic and the thesis statement to ensure that the work is feasible within agreed upon time frame.
- Discussing and evaluating hypotheses and methods.
- Advising on literature, source material, data, documentation, and resource requirements.
- Discussing the layout of the thesis with the student (disposition, linguistic form, etcetera).
- Discussing the results and the interpretation of them.
- Staying informed about the work progress and assist the student if necessary.
- Together with the student, keeping track of supervision hours spent.

The institute is responsible for

- Ensuring that the agreement is entered into.
- Find and appoint supervisor(s).
- Enter into an agreement with another department / faculty / institution if there is an external co-supervisor.
- In cooperation with the supervisor, keep an overview of the student's progress, the number of supervision hours. spent, and assist if the student is delayed by appointment.
- Appoint a new supervisor and arrange for a new agreement if:
  - The supervisor will be absent due to research term, illness, travel, etcetera.
  - The student or supervisor requests to terminate the agreement due to lack of adherence from either party.
  - Other circumstances where it is appropriate with a new supervisor.
- Notify the student when the agreement terminates.
- Inform supervisors about the responsibility for safeguarding ethical issues, privacy and guidance ethics
- Should the cooperation between student and supervisor become problematic, either party may apply to the department to be freed from the agreement. In such occurrence, the department must appoint a new supervisor

This Master`s agreement must be signed when the guidelines have been reviewed.

Signatures

Sindre Bjerkestrand Haugsvær
Student

14.03.2023
Digitally approved

Johanna Johansen
Supervisor

14.03.2023
Digitally approved

Hilde Bakke
Department

22.03.2023
Digitally approved

Appendix B

Focus Group Discussion Topics

Focus groups - Sustainable Web - First draft

Each subgroup has to appoint 3 participants responsible for:
1: Time keeping.
2: Flow of discussion. Including everyone.
3: Writing down the groups conclusion on each topic.

Four topics:

1. Code optimization and efficient coding techniques: Explore the techniques and strategies used by participants for optimizing code and enhancing performance, and discuss how these practices might contribute to energy efficiency in web development.

2. Integrating sustainability principles into project management: Discuss participants' experiences or opinions with incorporating sustainability principles into their project management processes. Include any challenges they have faced or could face, and potential benefits.

3. Tools and frameworks for performance optimization and energy efficiency: Identify existing tools, frameworks, or libraries that facilitate performance optimization and potentially support energy-efficient web development, and discuss their effectiveness and ease of use. If you know any.

4. Overcoming barriers to sustainable web development: Address potential obstacles that may be encountered when attempting to implement sustainability principles and performance optimization techniques. Brainstorm possible solutions or strategies for overcoming these challenges.

Focus Groups - Sustainable Web - Final Topics

Each group appoints 3 participants responsible for:
1: Facilitator: Directing the conversation to stay on topic. Make sure every member can contribute.
2: Time-keeper: Monitoring the time for each discussion. Stay on schedule.
3: Writer: Take notes and deliver them to the moderator.

Topics to discuss:

1. Code optimization and efficient coding techniques:
   - Do you know of, or use, any techniques or methods that optimize your code and enhance the performance of your product?
   Coding techniques / practices / other ideas?

2. Tools and frameworks for code/performance optimization:
   - Do you know any?
   For instance: Third-party-software, libraries, plugins, add-ons, extensions, packages etc.

3. Integrating these actions towards project management / development life cycle:
   - Do you know of any techniques/methods/tools/rituals that are (or could be) integrated into development life cycles?
   - Discuss potential challenges and benefits.
   For instance: Agile practices? Reviews and ceremonies? Automations? CI/CD

4. The actions discussed above may lower the carbon footprint of the end products, and increase sustainability awareness among practitioners.
   - Discuss how, if you have any thoughts on this.

5. Did you know anything about environmental sustainability within web technology before this session?
   - If so, what?
   - Would you like to learn more about these topics?
   - Do you see any potential obstacles in implementing/integrating sustainable practices?

If you have other related ideas? Fire away!

Appendix C

Research Ethics

Sikt

DATA MANAGEMENT PLAN

Master2023 - Sustainable Web Products

Disciplines
Technology

Research responsible institution
Norges teknisk-naturvitenskapelige universitet / Fakultet for informasjonsteknologi og elektroteknikk (IE) / Institutt for datateknologi og informatikk

Project duration
02.01.2023 — 01.06.2023

Purpose
Purpose: Investigate web sustainability and discover ways to ensure more sustainable web products. Propose a methodology based on the analyzed data. RQs: 1: What is the current status on the sustainability of the web, and what are common practices in the development and operation of web products today? 2: What principles and practices should be incorporated into an environmentally sustainable methodology for the development and operation of web products? Method: Data mainly collected through focus groups, and supplemented with data from literature review, publications by the "W3C Sustainability Community Group", and follow up conversations (semi-structured interviews).

Utility
Participants: Focus groups: Software developers working in the Technology department in Telenor. Semi-structured interviews: 1: Tech manager in Telenor 2: Co-chair of the "W3C Sustainable Web Design Community Group"

Ethical guidelines

- General guidelines for research ethics
- Science and Technology
- Internet Research

Focus group data

Description
Interpreted and translated notes from each of the three focus groups. 3 pages of text.

Data type
Text

Language
British English

Data about people
Yes

Are there any other reasons why your data needs extra protection?
No

Categories of personal data
Anonymous

Comment
The organizations associated with each participant and their respective roles are collected, while individual identities are anonymized.

Data collection period
03.04.2023 — 07.04.2023

Collection devices

- 6. Other data collection method

Method
Focus Group

Comment

Small text-file

Storage

- 01. Personal cloud storage (dropbox, google drive ++)

Transfer

- 4. Other transfer method

Comment

Stored in a personal cloud storage (Apple) for security data loss prevention

Archiving

Yes

Degree of openness

Open

Comment

Research data can be shared if requested. If not requested, data will be archived after publication.

Key data points from literature review

Description

Clear recommendations / findings in the literature, on actions that may be taken to ensure sustainable web products.

Data type

Text

Language

British English

Data about people

No

Are there any other reasons why your data needs extra protection?

No

Method

Summary

Comment

Small text-file

Storage

- 01. Personal cloud storage (dropbox, google drive ++)

Transfer

- 4. Other transfer method

Comment

Stored in a personal cloud storage (Apple) for security data loss prevention

Archiving

Yes

Degree of openness

Open

Comment

Research data can be shared if requested. If not requested, data will be archived after publication.

Key data points from the "W3C Sustainable Web Design Community Group"

Description

Retrieved from the community group's guidelines, which are in development.

Data type

Text

Language

American English

Data about people
No

Are there any other reasons why your data needs extra protection?
No

Method
Summary

Comment
Small text-file

Storage
- 01. Personal cloud storage (dropbox, google drive ++)

Transfer
- 4. Other transfer method

Comment
Stored in a personal cloud storage (Apple) for security data loss prevention

Archiving
Yes

Degree of openness
Open

Comment
Research data can be shared if requested. If not requested, data will be archived after publication.

Notes from semi-structured interviews

Description
1: Tech manager in Telenor (translated to English) 2: Co-chair of the "W3C Sustainable Web Design Community Group"

Data type
Text

Language
American English

Data about people
Yes

Are there any other reasons why your data needs extra protection?
No

Categories of personal data
Anonymous

Comment
The organizations associated with each participant and their respective roles are collected, while individual identities are anonymized.

Method
Interview

Comment
Small text-file

Storage
- 01. Personal cloud storage (dropbox, google drive ++)

Transfer
- 4. Other transfer method

Comment
Stored in a personal cloud storage (Apple) for security data loss prevention

Archiving
Yes

Degree of openness
Open

Comment
Research data can be shared if requested. If not requested, data will be archived after publication.

Informed Consent Form

Dear participant,

As part of my masters thesis in Applied Computer Science at NTNU, I am researching sustainable web technology, and strategies to reduce the carbon footprint of web products.

You are going to take part in a focus group session of a duration of approximately 40 minutes. The purpose with the session is to learn about your experiences and opinions, as a practitioner, on development techniques and methods that may promote sustainability.

The session will be conducted in hybrid format, during the OSS coding chapter meeting on Friday 14th of April. Participants will be split into groups, and asked to discuss 5 topics. All participants are encouraged to contribute to their subgroup, to create a discussion. You are free to share any knowledge that you might find relevant to the topics discussed.

Collection of data, purpose and processing
No questions that could identify you as an individual will be asked. All information will be anonymized. Each group will write down their conclusions, which will be collected and analyzed.

Voluntary participation and your rights
There are no known risks associated with your participation in this study. The study is anonymous and your participation is voluntary. You remain in full control of your actions and may leave the study without giving reasons, in which case all information gathered until then will be erased.

To give consent:
React to this attachment with a «thumbs up» in the Webex group «OSS Coding Chapter».

Thank you for your participation. Your contribution is very valuable for informing and advancing my research!

Best regards,
Sindre B. Haugsvær
Date: 14.04.23 *Contact information below:*

Contact:
The data protection officer at NTNU is Thomas Helgesen. He can be reached via email: thomas.helgesen@ntnu.no

Do not send sensitive information via e-mail. If you need to send sensitive information, contact the data protection officer via e-mail first.

Researcher:
Sindre Bjerkestrand Haugsvær
sindrbh@stud.ntnu.no
Norwegian University of Science and Technology

NTNU
Norwegian University of Science and Technology

Appendix D

Data Analysis

This appendix include working documents through the data analysis process:

1. Raw notes
2. Interpreted, translated and rewritten notes
3. Open Coding
4. Axial Coding
5. Additional Data Collection
6. Notes from semi-structured interview 1: With W3C member
7. Notes from semi-structured interview 2: With Telenor tech manager, open coded
8. Selective Coding

Focus Groups raw notes

Group 1 (online), notes:

1: Code optimization and efficient coding techniques

- Ja, vi har fokus på optimalisert kode
- F.eks ved bruk av SonarQube/Sonarlint
- Code review (Code with me)
- Bruk av caching (Redis)

2: Tools and frameworks for code/performance optimization

- SonarQube
- Bruk av MSSQL Server management studio for optimization
- Google's Web Packaging

3: Integrating the above towards project management / development life cycle

- CI/CD Pipeline
- Ansible Playbooks
- Diskuterte litt at for hver gang vi deployer nye versjoner så legger vi på mer CPU last på vårt kjøremiljø
- Vi har stort sett alle team alt for lite tid til kode optimalisering, da vi ofte har krav til kjappe leveranser ift T2M (Time to Market)

4: How may the actions above lower the carbon footprint of web products and increase awareness?

- Vi bør løfte utfordringene litt til våre ledere ift T2M og tidsbruk.
- Vi har et forslag til å sette opp et Grafana-board som viser strømforbruk pr team/namespace
- Dette kunne vært nyttig å presentert i sonen vår. Potensielt så kan det også benyttes i forbedringsformål. F.eks vise strømforbruk pr. applikasjon.

5: General discussion on sustainable web technology

- De fleste kjente ikke til dette før selve presentasjonen til Sindre.
- Mail og opprydding som alle burde ta ansvar for
- Hvordan kan vi kunne kvittet oss med uønsket mail som spam & reklame?
- Kanskje vi burde laget en AI tjeneste på mail serveren som kunne ryddet dette for oss?
- Dette ønsker vi å lære mer om.
- Telenor sin kommersielle rolle er en potensiell hindring i denne sammenheng (jo mer trafikk i nettet, jo mer penger tjener Telenor. Noe som igjen er uheldig i denne sammenheng.)

Group 2 (on site), notes:

1: Code optimization and efficient coding techniques

- Noen av våre systemer cacher responser fra baksystemer.
- Minified dokumenter og js, pluss komprimering
- Avro-skjemaer istedenfor Json
- Bruker gatling-tester for å kjøre mange kall på kort tid for å teste ytelse.
- Container-teknologi, som f.eks. å bare starte så mange podder man trenger.
- Edge-computing, som f.eks. Netflix.
- Mer effektive kompilatorer.

2: Tools and frameworks for code/performance optimization

- Komprimering av bilde og lyd, f.eks. med andre standarder. SVG eller WebP for bilde.
- Java17 (bedre garbage collector).
- Mac bruker ny prosessor som bruker mindre strøm.
- Kafka er kanskje mer energi-effektivt.
- Grafana for å følge med på relevante metrikker (f.eks. responstid og minnebruk).
- Kanskje mer kjerne-kraft som strømkilde til PC/Mobil.

3: Integrating the above towards project management / development life cycle

- SonarQube som sjekker etter lite effektiv kode.
- Ukentlig nattlig bygg istedenfor daglige og nattlige bygg.
- Digitale møter istedenfor fysiske.
- Kanskje prøve å gjøre cronjobber (og lignende) mer effektive.

4: How may the actions above lower the carbon footprint of web products and increase awareness?

- F.eks. hvis vi har Grafana skjerm kan vi lettere følge med på endringer.
- f.eks. page load eller page weight.

5: General discussion on sustainable web technology

- Et hinder for sustainability er at det kanskje kommer i veien for lønnsomhet
- Kjølevannet fra superdatamaskiner hos NTNU varmer opp byggene.
- Krypto er ikke strømvennlig.

Group 3 (online), notes:

1: Code optimization and efficient coding techniques

- Mye rekompilering, på klientsiden bruker man cashing av data
- Prøver å optimalisere databasespørringer i stede for å filtrere i backend (mindre data)
- Tykke og tynne objekter(mulighet for å ikke alltid sende all data man har)
- Binær søk mer effektivt enn å gå gjennom hvert element hver for seg

2: Tools and frameworks for code/performance optimization

- Cashing i frontend Usequery,
- Sonarlint gir tilbakemelding om ueffetiv/overflødig kode samme med sonarqube
- Kafka mindre api kall, men bør passe på å slette meldinger på kø
- Vite, devtools skjer bare lokalt(hvor mye har det da å si?) (https://vitejs.dev/)
- Darkmode eller lightmode
- Bytte farge på logo (rød telenor!)

3: Integrating the above towards project management / development life cycle

- Designer har mye å si, tenke på hvilken data man trenger når man lager designet, tenke på effektivitet før man starter på oppgaven
- Programmeringsspråk kan ha noe å si, det finnes språk med lavere footprint
- Microservices, for å unngå en stor service som krever masse info
- Docker en stor synder på green tech
- Code review, tenke på performance når man leser gjennom
- Ta hensyn til effektivitet ved valg av leverandør
- Jenkins lager ikke et bygg automatisk for commit
- Sette services i idle

4: How may the actions above lower the carbon footprint of web products and increase awareness?

- Show & tell presentations / sessions at work.
- Lage standarer på hvordan ting skal være, defaultregler, tenke på hvor mye ressurser du trenger for å kjøre podder f. eks
- Etter en viss ineffektivitet slår man av systemer, tar litt tid for første som bruker det, men er nok få som bruker det visse klokkeslett (før kl 8, etter 16)
- Servere. Flere kjøpte systemer tar betaling for mengde. Kan spare penger også her, dette er også vanlig blant skytjenester
- Ofte kjører bare PCen hele helgen, utviklere gjøre en innsats for å ikke kjøre ting hele tiden
- Få store selskaper til å promotere sustainability

5: General discussion on sustainable web technology

- Så på presentasjonen
- Visste at svarte piksler sparer strøm,
- Slette eposter, bruker mye strøm på servere
- Bruke darkmode i større grad, ta hensyn til dette i designfasen
- Bitcoin er ille

Focus Groups notes - Interpretation, translation and rewriting

Group 1 (online), notes:

1: Code optimization and efficient coding techniques

- Code optimization is an area of focus
- Tools like SonarQube and SonarLint are frequently used, providing continuous code quality inspection and automated code review capabilities, identifying potential code inefficiencies.
  - https://docs.sonarqube.org/latest/
  - https://www.sonarsource.com/products/sonarlint/
- Code review techniques with the use of a tool called "Code With Me", allowing for collaborative examination of code to ensure optimal coding practices.
  - https://www.jetbrains.com/code-with-me/
- The group uses Redis as a caching tool to enhance the performance of their applications by storing frequently accessed data in memory, reducing unnecessary data retrieval operations.
  - https://redis.io/

2: Tools and frameworks for code/performance optimization

- Again, SonarQube and SonarLint
- SQL Server Management Studio is used to manage and optimize SQL infrastructure
  - (https://learn.microsoft.com/en-us/sql/ssms/download-sql-server-management-studio-ssms?view=sql-server-ver16)
- Google's Web Packaging technology is utilized, potentially offering benefits like faster load times and improved user experience.

3: Integrating the above towards project management / development life cycle

- A Continuous Integration/Continuous Delivery (CI/CD) pipeline is in place, facilitating automated testing and deployment of their applications.
- Ansible Playbooks for IT infrastructure and application deployment
  - (https://docs.ansible.com/ansible/latest/playbook_guide/playbooks_intro.html)
- The group stated that there are challenges associated with deploying new versions frequently, as it increases CPU load on their environment.
- Lack of time and resources to prioritize code optimization, as the requirements for rapid delivery (time to market) is more important

4: How may the actions above lower the carbon footprint of web products and increase awareness?

- The group pointed out that these challenges should be discussed with the management, especially regarding «time to market» and the prioritization of sustainable practices.
- One suggestion is to develop a Grafana-dashboard in the department, showing live energy consumption per team or per application. This could increase awareness and push teams in the direction of developing more energy efficient products.
  - https://grafana.com/

5: General discussion on sustainable web technology

- The majority of the group were not familiar with sustainable web technology before Sindre's presentation.
- The group recognizes the challenge related to the email industry and storage of unnecessary data, consuming large amounts of energy. They discussed methods to clean this up, especially spam mails and advertisement. Perhaps utilizing or developing an AI service that could do this is a solution.
- The group wish to learn more about sustainable web technologies.
- Telenor's commercial interests could potentially pose a challenge in this context, as the company stands to profit from increased network traffic. This may not align with the sustainability goals.

Group 2 (on site), notes:

1: Code optimization and efficient coding techniques

- The group utilizes caching in some of their systems to store responses from backend systems, improving speed and reducing the load on those systems.
- They suggested using minified documents and JavaScript along with compression techniques to reduce the size of files and speed up load times.
- They suggested using Avro schemas instead of JSON for data serialization, which may lead to reduced data transfer.
- The group brought up Gatling, a powerful tool for load and stress testing, to evaluate system performance.
- The utilization of container technology, like launching only as many pods as needed, was highlighted as a potential approach to optimize resource use.
- They noted the potential benefits of edge-computing, where computation is performed closer to the data source, reducing latency and bandwidth use.
- They suggested that more efficient compilers may optimize performance.

2: Tools and frameworks for code/performance optimization

- They suggested using image and sound compression techniques, e.g., using formats like SVG or WebP for images.
- They acknowledged the improved garbage collector in Java 17 as an upgrade that could potentially reduce memory usage.
- They recognized that new processors, such as those used by Apple in their new Macs, can be more power-efficient.
- They considered that Kafka might be more energy-efficient for data streaming tasks.
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3: Integrating the above towards project management / development life cycle

- The use of SonarQube for detecting inefficient code was discussed as a potential approach to ensure code quality.
- They suggested adopting weekly night builds instead of daily and night builds to conserve resources.
- The group brought up the potential benefits of holding digital meetings instead of physical ones to reduce carbon emissions related to travel.
- They also discussed making cron jobs (and similar processes) more efficient to improve resource usage.

4: How may the actions above lower the carbon footprint of web products and increase awareness?

- They proposed the idea of implementing a Grafana dashboard to allow for real-time monitoring of energy consumption. Page load times or page weight could be visualized.

5: General discussion on sustainable web technology

- A hindrance to sustainability is that it might get in the way of profitability.
- The cooling water from supercomputers at NTNU heats the buildings.
- The group noted the high power consumption of cryptocurrencies, acknowledging the environmental implications of such technologies.

Group 3 (online), notes:

1: Code optimization and efficient coding techniques

- The group discussed the advantages of caching data on the client side
- They discussed optimizing database queries as a preferable alternative to filtering data in the backend, emphasizing the advantages of processing less data.
- They talked about the concept of 'thick' and 'thin' objects, suggesting that not all available data needs to be sent at once, thus optimizing data transfer.
- They pointed out that binary search can be more efficient than linear search, as it doesn't need to go through each element one by one.

2: Tools and frameworks for code/performance optimization

- They proposed using caching in the frontend with tools like Usequery (custom React hook) to speed up application performance.
- Tools such as SonarLint and SonarQube were suggested for identifying inefficient or redundant code.
- They acknowledged the potential of Kafka in reducing API calls and the importance of managing the message queue to prevent data overflow.
- They mentioned Vite.js, a web development tool (dev server and bundler) designed for modern JavaScript frameworks like Vue and React. It offers fast workflow in the development phase, and is an alternative for Webpack and Parcel, which may be better for bigger projects.
  - https://vitejs.dev/
- They considered the benefits of implementing dark or light mode options for power saving and also touched upon color usage in UI design.

3: Integrating the above towards project management / development life cycle

- The group recognized the critical role of designers in driving efficiency, emphasizing the importance of considering data requirements in the design phase.
- They acknowledged that the choice of programming language may impact a product's carbon footprint, noting that some languages may have lower footprints.
- Microservices were suggested as a possible strategy to avoid creating large, resource-intensive services.
- They argued that Docker and similar technologies may contribute to overconsumption of resources, due to the ease and speed of setting up containers.
- They discussed the value of code review for performance optimization and the need to consider efficiency when choosing suppliers.
- They suggested that automation tools such as Jenkins, should be configured so it does not automatically build for every new commit. Frequent builds may be a waste of computational resources and energy.
- The idea of setting services to idle during periods of inactivity was also suggested.

4: How may the actions above lower the carbon footprint of web products and increase awareness?

- The group proposed incorporating best practices for sustainability into "Show & Tell" presentations at work to spread awareness.
- They suggested creating default rules and standards for resource utilization, such as establishing guidelines for running pods.
- The group discussed the possibility of shutting down systems during periods of low usage, such as during night time.
- The company's reliance on many services, particularly cloud services, which are billed on a pay-per-usage basis rather than fixed-term contracts, underscores the potential for both financial savings and reduced environmental impact through more efficient utilization.
- The group recognized the potential energy waste in leaving hardware running continuously, especially through weekends, and suggested that developers could take active steps to prevent this.
- Also, they suggested that large companies could promote sustainability. This could increase awareness among many practitioners.

5: General discussion on sustainable web technology

- The group did not have much knowledge in sustainable web technology prior to the presentation given
- The group also brought up the challenges in the email industry.
- They knew that dark pixels consumed less energy, and suggested increased usage of dark mode. At least, this should be considered in design phases.
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Focus Groups notes - Open Coding

Categories:	Codes:	Number of comments
Coding Techniques / Tools / Frameworks	C	31
Deployment / Integration / Automation	D	8
Awareness	A	6
General Thoughts / Other Ideas	G	21
	Sum:	66

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3: Integrating the above towards project management / development life cycle

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3: Integrating the above towards project management / development life cycle

- The use of SonarQube for detecting inefficient code was discussed as a potential approach to ensure code quality.
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Focus Groups notes - Axial Coding

Categories:	Codes:	Number of comments
Code Review / Code Quality	C1	6
Caching	C2	4
Backend	C3	11
Frontend	C4	8
Deployment / Integration / Automation	D	10
Awareness	A	6
General Thoughts / Other Ideas	G	3
Planning / Design	P	3
To Management	M	4
	Sum:	55

Coding techniques / tools / frameworks

C1 - Code review / code quality:

- Code optimization is an area of focus
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  - https://www.sonarsource.com/products/sonarlint/
- SonarLint mentioned again
- Tools such as SonarLint were suggested for identifying inefficient or redundant code.
- Code review techniques with the use of a tool called "Code With Me", allowing for collaborative examination of code to ensure optimal coding practices.
  - https://www.jetbrains.com/code-with-me/
- They discussed the value of code review for performance optimization and the need to consider efficiency when choosing suppliers.

C2 - Caching:

- The group uses Redis as a caching tool to enhance the performance of their applications by storing frequently accessed data in memory, reducing unnecessary data retrieval operations.
  - https://redis.io/
- The group utilizes caching in some of their systems to store responses from backend systems, improving speed and reducing the load on those systems.
- The group discussed the advantages of caching data on the client side
- They proposed using caching in the frontend with tools like Usequery (custom React hook) to speed up application performance.

C3 - Backend:

- SQL Server Management Studio is used to manage and optimize SQL infrastructure
  - (https://learn.microsoft.com/en-us/sql/ssms/download-sql-server-management-studio-ssms?view=sql-server-ver16)
- Google's Web Packaging technology is utilized, potentially offering benefits like faster load times and improved user experience.
- The group brought up Gatling, a powerful tool for load and stress testing, to evaluate system performance.
- They argued that Docker and similar technologies may contribute to overconsumption of resources, due to the ease and speed of setting up containers …
- Therefore … the utilization of container technology, is like launching only as many pods as needed, was highlighted as a potential approach to optimize resource use.

- They acknowledged the improved garbage collector in Java 17 as an upgrade that could potentially reduce memory usage.
- They considered that Kafka might be more energy-efficient for data streaming tasks.
  - https://kafka.apache.org/
- They acknowledged the potential of Kafka in reducing API calls and the importance of managing the message queue to prevent data overflow.
- They also discussed making cron jobs (and similar processes) more efficient to improve resource usage.
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C3 - Frontend:
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- They suggested using image and sound compression techniques, e.g., using formats like SVG or WebP for images.
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- They talked about the concept of 'thick' and 'thin' objects, suggesting that not all available data needs to be sent at once, thus optimizing data transfer.
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- They acknowledged that the choice of programming language may impact a product's carbon footprint, noting that some languages may have lower footprints.

D - Deployment / Integration / Automation
- A Continuous Integration/Continuous Delivery (CI/CD) pipeline is in place, facilitating automated testing and deployment of their applications.
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- The group stated that there are challenges associated with deploying new versions frequently, as it increases CPU load on their environment.
- The use of SonarQube for detecting inefficient code was discussed as a potential approach to ensure code quality.
- They suggested that automation tools such as Jenkins, should be configured so it does not automatically build for every new commit. Frequent builds may be a waste of computational resources and energy.
- SonarQube used in the building phase for automated quality control.
  - https://docs.sonarqube.org/latest/
- SonarQube, mentioned again
- SonarQube, mentioned yet again
- They suggested adopting weekly night builds instead of daily and night builds to conserve resources.
- The group debated the idea of using more sustainable energy sources, like nuclear power, for powering data centers and end devices.

A - Awareness

- One suggestion is to develop a Grafana-dashboard in the department, showing live energy consumption per team or per application. This could increase awareness and push teams in the direction of developing more energy efficient products.
  - https://grafana.com/
- Grafana was discussed as a tool for monitoring relevant metrics, such as response time and memory usage, to assist in application optimization.
- They proposed the idea of implementing a Grafana dashboard to allow for real-time monitoring of energy consumption. Page load times or page weight could be visualized.
- The group proposed incorporating best practices for sustainability into "Show & Tell" presentations at work to spread awareness.
- They suggested creating default rules and standards for resource utilization, such as establishing guidelines for running pods.
- Also, they suggested that large companies could promote sustainability. This could increase awareness among many practitioners.

G - General thoughts / other ideas

- The majority of the group were not familiar with sustainable web technology before Sindre's presentation.
- The group did not have much knowledge in sustainable web technology prior to the presentation given
- The group wish to learn more about sustainable web technologies.

P - Planning / Design

- The group recognized the critical role of designers in driving efficiency, emphasizing the importance of considering data requirements in the design phase.
- They knew that dark pixels consumed less energy, and suggested increased usage of dark mode. At least, this should be considered in design phases.
- They considered the benefits of implementing dark or light mode options for power saving and also touched upon color usage in UI design.

M - To Management - Challenges - desired areas for improvement

- Lack of time and resources to prioritize code optimization, as the requirements for rapid delivery (time to market) is more important
- The group pointed out that these challenges should be discussed with the management, especially regarding «time to market» and the prioritization of sustainable practices.
- Telenor's commercial interests could potentially pose a challenge in this context, as the company stands to profit from increased network traffic. This may not align with the sustainability goals.
- A hindrance to sustainability is that it might get in the way of profitability.

O - Other: Irrelevant to web development and operations

- The group recognizes the challenge related to the email industry and storage of unnecessary data, consuming large amounts of energy. They discussed methods to clean this up, especially spam mails and advertisement. Perhaps utilizing or developing an AI service that could do this is a solution.
- The group also brought up the challenges in the email industry.
- The cooling water from supercomputers at NTNU heats the buildings.
- They noted the potential benefits of edge-computing, where computation is performed closer to the data source, reducing latency and bandwidth use.
- They recognized that new processors, such as those used by Apple in their new Macs, can be more power-efficient.
- The group noted the high power consumption of cryptocurrencies, acknowledging the environmental implications of such technologies.
- The group recognized the potential energy waste in leaving hardware running continuously, especially through weekends, and suggested that developers could take active steps to prevent this.

- The company's reliance on many services, particularly cloud services, which are billed on a pay-per-usage basis rather than fixed-term contracts, underscores the potential for both financial savings and reduced environmental impact through more efficient utilization.
- The group discussed the possibility of shutting down systems during periods of low usage, such as during night time.
- The idea of setting services to idle during periods of inactivity was also suggested.
- Lastly, they mentioned the high energy consumption of cryptocurrencies.
- The group brought up the potential benefits of holding digital meetings instead of physical ones to reduce carbon emissions related to travel.

Focus Groups notes - Additional Data Collection

Categories:	Codes:	Number of comments
Planning / Design	P	9
Coding (General, Frontend, Backend)	C	60
Operation	O	18
Management/Business/Strategy (Awareness, Challenges and strategies, Current knowledge)	M	26
Sum:		113

New sources
Data from the new sources are put into fitting categories, and marked in the following colors:
Member of the «W3C Sustainable Web Design Community Group»
W3C Sustainable Web Guidelines - Drafts.
Available here: https://www.w3.org/community/sustyweb/wiki/Main_Page
Tech Manager - Telenor
Literature Review

Comments:
Moved caching-comments into frontend, as caching it is usually a frontend task
«Deployment / Integration / Automation» renamed to «Operation»
Merged «Awareness», «General thoughts» and «Management» into «Management/Business/ Strategy». Changed title of «General thoughts» to «Current knowledge», as most comments were related to knowledge.
Changed order of groups. P, C, O, M
Renamed «Code review / code quality:» to «General coding practices/tools for optimization»

P - Planning / Design
- The group recognized the critical role of designers in driving efficiency, emphasizing the importance of considering data requirements in the design phase.
- They knew that dark pixels consumed less energy, and suggested increased usage of dark mode. At least, this should be considered in design phases.
- They considered the benefits of implementing dark or light mode options for power saving and also touched upon color usage in UI design.
- UX Design guidelines (W3C UX Design Committee):
  - Assign a sustainability representative
  - Estimate the environmental impact
  - Ensure navigation and way-finding is well-structured
  - Prefer a simple web design using recognized patterns
  - Ensure any image assets are sustainable
  - Ensure any multimedia assets are sustainable

C - Coding
General coding practices/tools for optimization:
- Code optimization is an area of focus
- Tools like SonarLint is frequently used, providing continuous code quality inspection and automated code review capabilities, identifying potential code inefficiencies.
  - https://www.sonarsource.com/products/sonarlint/
- SonarLint mentioned again
- Tools such as SonarLint were suggested for identifying inefficient or redundant code.
- Code review techniques with the use of a tool called "Code With Me", allowing for collaborative examination of code to ensure optimal coding practices.
  - https://www.jetbrains.com/code-with-me/
- They discussed the value of code review for performance optimization and the need to consider efficiency when choosing suppliers.

Frontend:

- The group uses Redis as a caching tool to enhance the performance of their applications by storing frequently accessed data in memory, reducing unnecessary data retrieval operations.
  - https://redis.io/
- The group utilizes caching in some of their systems to store responses from backend systems, improving speed and reducing the load on those systems.
- The group discussed the advantages of caching data on the client side
- They proposed using caching in the frontend with tools like Usequery (custom React hook) to speed up application performance.
- They suggested using minified documents and JavaScript along with compression techniques to reduce the size of files and speed up load times.
- They suggested using image and sound compression techniques, e.g., using formats like SVG or WebP for images.
- They suggested using Avro schemas instead of JSON for data serialization, which may lead to reduced data transfer.
- They discussed optimizing database queries as a preferable alternative to filtering data in the backend, emphasizing the advantages of processing less data.
- They talked about the concept of 'thick' and 'thin' objects, suggesting that not all available data needs to be sent at once, thus optimizing data transfer.
- They pointed out that binary search can be more efficient than linear search, as it doesn't need to go through each element one by one.
- They mentioned Vite.js, a web development tool (dev server and bundler) designed for modern JavaScript frameworks like Vue and React. It offers fast workflow in the development phase, and is an alternative for Webpack and Parcel, which may be better for bigger projects.
  - https://vitejs.dev/
- They acknowledged that the choice of programming language may impact a product's carbon footprint, noting that some languages may have lower footprints.
- 10 general frontend coding guidelines (W3C Web Development Committee):
  - Minify HTML, CSS, JS
  - Optimize browser caching
  - Compress files
  - Code-splitting within projects
  - Tree shaking
  - Ensure content and code are accessible
  - Avoid code duplication
  - Set project sustainability budget
  - Avoid using plug-ins or inefficient third party tooling
  - Use error pages and redirects carefully
- 5 specific HTML guidelines (W3C Web Development Committee):
  - Use HTML elements correctly
  - Lazy Load render blocking content
  - Provide suitable way-finding mechanisms
  - Validate from errors and external input
  - Use various metadata correctly
- 2 specific CSS guidelines (W3C Web Development Committee):
  - Use CSS preference & media queries
  - Develop a mobile-first layout
- 4 specific JavaScript guidelines (W3C Web Development Committee):
  - Avoid unethical coding techniques
  - Use beneficial JavaScript & its API's
  - Ensure your scripts are secure
  - Manage dependencies
- Other relevant guidelines (W3C Web Development Committee):
  - Provide suitable alternatives to media formats
  - Avoid unnecessary or an overabundance of assets
- Compress assets, reduce the weight and opt for sustainable formats
- Code splitting, tree shaking, server-side rendering
- Efficient caching strategies
- Opt for green CDN's
- Lazy loading

Backend:

- SQL Server Management Studio is used to manage and optimize SQL infrastructure
  - (https://learn.microsoft.com/en-us/sql/ssms/download-sql-server-management-studio-ssms?view=sql-server-ver16)
- Google's Web Packaging technology is utilized, potentially offering benefits like faster load times and improved user experience.
- The group brought up Gatling, a powerful tool for load and stress testing, to evaluate system performance.
- They argued that Docker and similar technologies may contribute to overconsumption of resources, due to the ease and speed of setting up containers …
- Therefore … the utilization of container technology, is like launching only as many pods as needed, was highlighted as a potential approach to optimize resource use.
- They acknowledged the improved garbage collector in Java 17 as an upgrade that could potentially reduce memory usage.
- They considered that Kafka might be more energy-efficient for data streaming tasks.
  - https://kafka.apache.org/
- They acknowledged the potential of Kafka in reducing API calls and the importance of managing the message queue to prevent data overflow.
- They also discussed making cron jobs (and similar processes) more efficient to improve resource usage.
- Microservices were suggested as a possible strategy to avoid creating large, resource-intensive services.
- They suggested that more efficient compilers may optimize performance.
- 3 general backend coding guidelines (W3C Web Development Committee):
  - Use the latest stable language version
  - Take advantage of native features
  - Run fewer, simpler queries as possible

O - Operation

- A Continuous Integration/Continuous Delivery (CI/CD) pipeline is in place, facilitating automated testing and deployment of their applications.
- Ansible Playbooks for IT infrastructure and application deployment
  - (https://docs.ansible.com/ansible/latest/playbook_guide/playbooks_intro.html)
- The group stated that there are challenges associated with deploying new versions frequently, as it increases CPU load on their environment.
- The use of SonarQube for detecting inefficient code was discussed as a potential approach to ensure code quality.
- They suggested that automation tools such as Jenkins, should be configured so it does not automatically build for every new commit. Frequent builds may be a waste of computational resources and energy.
- SonarQube used in the building phase for automated quality control.
  - https://docs.sonarqube.org/latest/
- SonarQube, mentioned again
- SonarQube, mentioned yet again
- They suggested adopting weekly night builds instead of daily and night builds to conserve resources.
- The group debated the idea of using more sustainable energy sources, like nuclear power, for powering data centers and end devices.
- Relevant guidelines on sustainable hosting & infrastructure (W3C Hosting, Infrastructure, Systems Committee):
  - Choose a sustainable hosting provider
  - Limit usage of additional environments
  - Automate to fit the needs
  - Use edge computing
- Adopt green energy sources / green hosting
- Modernization of IT systems. Hardware. Installation of hardware for the cloud. Move systems to the cloud. Can spin up and down VMs in the cloud. We only start the necessary number of VMs. "pods"
- Reduces consumption when needed is low. Instead of having them running all the time

- Many shared services in the cloud. Avoid having your own things per area. More energy efficient. Cost-saving. Less purchase of system. Cloudification is important. Developer/Ops.

M - Management/Business/Strategy

Awareness

- One suggestion is to develop a Grafana-dashboard in the department, showing live energy consumption per team or per application. This could increase awareness and push teams in the direction of developing more energy efficient products.
  - https://grafana.com/
- Grafana was discussed as a tool for monitoring relevant metrics, such as response time and memory usage, to assist in application optimization.
- They proposed the idea of implementing a Grafana dashboard to allow for real-time monitoring of energy consumption. Page load times or page weight could be visualized.
- The group proposed incorporating best practices for sustainability into "Show & Tell" presentations at work to spread awareness.
- They suggested creating default rules and standards for resource utilization, such as establishing guidelines for running pods.
- Also, they suggested that large companies could promote sustainability. This could increase awareness among many practitioners.
- Introduce and follow guidelines by the «W3C Sustainable Web Design Community Group» to increase awareness
  - Through «Learning hours» or seminars arranges by companies?
- Attend/follow the Annual W3C Conference (TPAC) conference in September (https://www.w3.org/2023/09/TPAC/)

Challenges and strategies

- Lack of time and resources to prioritize code optimization, as the requirements for rapid delivery (time to market) is more important
- The group pointed out that these challenges should be discussed with the management, especially regarding «time to market» and the prioritization of sustainable practices.
- Telenor's commercial interests could potentially pose a challenge in this context, as the company stands to profit from increased network traffic. This may not align with the sustainability goals.
- A hindrance to sustainability is that it might get in the way of profitability.
- Follow the proposed guidelines by the «W3C Business Strategy, Product Management Committee» (20 guidelines)
- Track sustainability progress through KPIs
- Following/focusing on SDGs are important
- Create a culture of environmental responsibility
- Sustainability also becomes part of the product. I think it will be pushed forward gradually. Above customers too. They must be secured. Will surely be a requirement with customers. Especially in the business market, but also the consumer market.
- When someone boasts that they are good at something, it makes the product more attractive.
- Teams can work closer with business-departments, achieving faster time-to-market and closer collaboration. And also align with sustainability-goals. BizDevOps.
- Sustainability champions could be a good idea, first focusing on areas with the biggest potential and needs. For instance cloud systems.
- Then, the message and culture may spread throughout the organization.
- In IT and web dev, following ISO-standards is demanding since they are behind a paywall

Current knowledge

- The majority of the group were not familiar with sustainable web technology before Sindre's presentation.
- The group did not have much knowledge in sustainable web technology prior to the presentation given
- The group wish to learn more about sustainable web technologies.
- Need to learn more about sustainable practices in web technologies, build knowledge in this area, and stay at the forefront of advancements in the field.

Semi-structured interview with a member of the W3C «Sustainable Web Design Community Group»
Role: Web developer / passionate about sustainability
Type of meeting: Digital, Zoom.

Informed consent form - Ok
(Can withdraw at any time. No personal data will be collected. The meeting will be transcribed / taken notes - not recorded)

Discussion / topics to guide the conversation:
- General conversation on sustainable web technologies, and practices to improve web sustainability.
- W3C and guidelines, standards, reports
- How these guidelines may be adopted

Meeting notes
The goals of the community group are to make guidelines equivalent to WCAG, but for sustainability.
The group is aiming to have them published this fall, as part of the TPAC conference in September 2023. https://www.w3.org/2023/09/TPAC/

The W3C Sustainable Web Design Community Group has 5 committees, as linked to here: https://www.w3.org/community/sustyweb/wiki/Main_Page
- UX Design
- Web Development
- Hosting, Infrastructure, Systems
- Analytics, Measurement, Reporting
- Business Strategy, Product Management

They all produce guidelines specific for their field, and will be published together as a W3C Sustainability Guidelines / Specification.
They cover not only environmental sustainability, but also social sustainability, diversity, etc.

Lots of individual professionals involved, as well as some large companies like Microsoft, Salesforce, Mozilla and Google.
Also, W3C members who have offered guidance in other fields are guiding the process of creating the guidelines.
The end result will be a «Non standardized report». However, in the future, one goal is to develop it into a open access web standard (in contrast to ISO standards).

ISO standards are behind a «paywall», which strides against the «open-source/open access/open learning environment» fundamentals of the web. These cost barriers may hinder smaller businesses and individuals in following these.

«Allowing people to help improve through open source has shown to be the best approach to progress».

Therefore, the community group considers to integrate/aligning their guidelines with the standards created by the Global Reporting Initiative (GRI) (https://www.globalreporting.org/). This may increase the credibility of following the guidelines.

In the future, a working group that focus specifically on producing a standard could be created.

Semi-structured interview with Telenor tech manager - Open coding
Role: Manager, technology
Type of meeting: Digital, Teams.

Informed consent form - Ok
(Can withdraw at any time. No personal data will be collected. The meeting will be transcribed / taken notes - not recorded)

Codes:	Categories:
P	Planning / Design
C	Coding techniques / tools / frameworks (General, Frontend, Backend)
O	Operation
M	Management/Business/Strategy (Awareness, Challenges and strategies, Current knowledge)

Intro:
Web sustainability.
Goal: making more sustainable web products. Proposing a DevOps variant with emphasis on sustainability. Reduced data transfer, green hosting, energy-efficient coding practices that makes products operate with a lower footprint.
PS: Direct footprint of the development process is out of scope. E.g energy consumption of hardware, office equipment, transportation etc.

Questions:
1:
I know that sustainability is one of Telenors «must win battles» (?). Do you have any examples of measures that are taken? Are some of them related to development and operation of systems/ web services?
- Gjøre noe med utslippene til entreprenører / graving / utbygging. Sette krav til underleverandører. Jobbes mye med. Elektriske gravemaskiner.
- Modernisering av IT systemer. Hardware. Installasjon av hardware til skyen. Flytte systemer til skyen. Kan spinne opp og ned VM'er I skyen. Starter vi bare nødvdig antal VM'er. «Poder»
  - Reduserer forbruket når behovet er lavt. I stede for å ha de kjørende hele tiden
  - Mye felles-tjenester i skyen. Slipper å ha egne greier pr område. Mer energi-effektivt. Kostnads-sparende. Mindre innkjøp av system. Cloudifisering er viktig. Dev/Ops.
- Kutting av kobbernettet. Modernisering. Frem til 2023. Slå av kobbertjenester. Slå av gamle systemer som er energikrevende. Også flytte ut av små lokasjoner med koblingspunkt. Kobler om. Leverer fortsatt noen kobbertjenester via wholesale. Fases fortsatt ut. Ta ned kabler? Også involverer å slå av mye utstyr som er veldig energikrevende.
  - Norge vs andre land? Tror at Norge er første land til å slå av. Alle har slått av. Telenor plikter å levere til underleverandører. Telenor er i front i verdensmålestokk.

2:
Prioritizing sustainability in the phases of the development life cycle may lead to down-prioritizing of other tasks. How do we justify it, and convince the leaders?
- Security er godt eksempel. Stort press på levere i markedet. Hvordan tid til å levere sikre systemer? Nå er det snudd: en del av tenkemåte til utviklere. Må ta sikkerhet kontinuerlig. Må patches kontinuerlig. En del av produktet.
- Sustainability blir også en del av produktet. Tror det vil bli presset frem gradvis. Ovenfor kunder også. De må sikres. Blir sikkert et krav hos kunder. Spesielt i bedriftsmarkedet, men og forbrukermarkedet.
- Når noen skilter med at de er gode på noe gjør det produktet mer attraktivt.

3:
Compare it to security. Security champions? DevSecOps. Thoughts? How is DevSecOps practiced in Telenor?

- Dagligtale: DevOps. For å få den tankegangen til utviklere. Må forvalte kode og. Vi kan la være å si DevSecOps, men det er en del av arbeidsmåten. Lage sikkerhetsmessig god kode, ivareta sikkerhet - gjør vi.
- Forretning tett i team - biz
- Sec champs - vi har det. Den rollen har nok ikke tatt helt av enda. Satt opp av security-avdeling. Kommer litt på siden. De har spesiell kompetanse og får sikkerhetsmessig påfyll - skape en sikkerhetskultur. Fokus på sec har vi fått godt inn i utviklerteamet.

4:
Could sustainability champions be an idea? Ensuring energy-efficient (and maybe cost saving) measures in design, dev and ops. Corporate responsibility, SDGs. Maybe a variant of BizDevOps would be better suited? See figures below.

- Ikke en dum idé. Også med security. Noen kunne begynt med det. Starte med de områdene med størst behov, eller måter å forbedre sustainability. Feks i cloud-systemer. Budskapet kan sprees til de resterende teamene. Hva kan teamene gjøre for å forbedre sustainability i kode, og hvordan gjøres det egentlig?

W3C-Sustainability-Guidelines blir antakeligvis publisert til høsten. Hva tenker du om det?
- Interresant. Store selskaper kan sikkert bruke dette fremover. Være i forkant.

Focus Groups notes - Selective Coding

Aim: Discover a core category that is related to all the subcategories

Categories:	Codes:	Number of comments
Planning / Design	P	9
Coding (General, Frontend, Backend)	C	60
Operation	O	18
Management/Business/Strategy (Awareness, Challenges and strategies, Current knowledge)	M	26
Sum:		113

Comments:
It is clear that the categories defined through the coding iterations align pretty much with the principles and steps of a DevOps oriented approach. The findings and experiences discovered in each category can be employed to individual steps. Looking at the number of comments in each category, coding-related comments come out on top - indicating that there is already knowledge of sustainable practices in this category. However, this is also the category that revealed the most areas of improvement.

The «M»-category had surprisingly many comments, indicating that there are both challenges and opportunities related to sustainability at management level. Also, it indicates that the awareness is already there, but perhaps missing concrete measures. It is evident that there is a knowledge gap in the industry, and that in order to increase focus on sustainability, educating professionals is important. Maybe taking action at the management level is necessary to drive the development in a more sustainable direction and create a culture for sustainable development.

Based on all the data points, it would be possible to form a list of actions linked to the steps of a DevOps approach, such as BizDevOps.

Sustainability-Enhanced BizDevOps		
The phases of BizDevOps:	**Core Categories of the Study**	**W3C Sustainable Web Design Committees:**
Idea	Management/Business/ Strategy	Business Strategy, Product Management
UI/UX Design	Planning / Design	UX Design
Plan		Business Strategy, Product Management
Code	Coding (General, Frontend, Backend)	Web Development
Build		
Test		
Release		
Deploy	Operation	Hosting, Infrastructure, Systems
Operate		
Monitor		
Feedback	Management/Business/ Strategy	Business Strategy, Product Management
Analyze		

The concrete guidelines developed by the W3C community group may serve as guidelines for each step of the methodology, complemented the actions suggested by the focus group participants and the interviews.

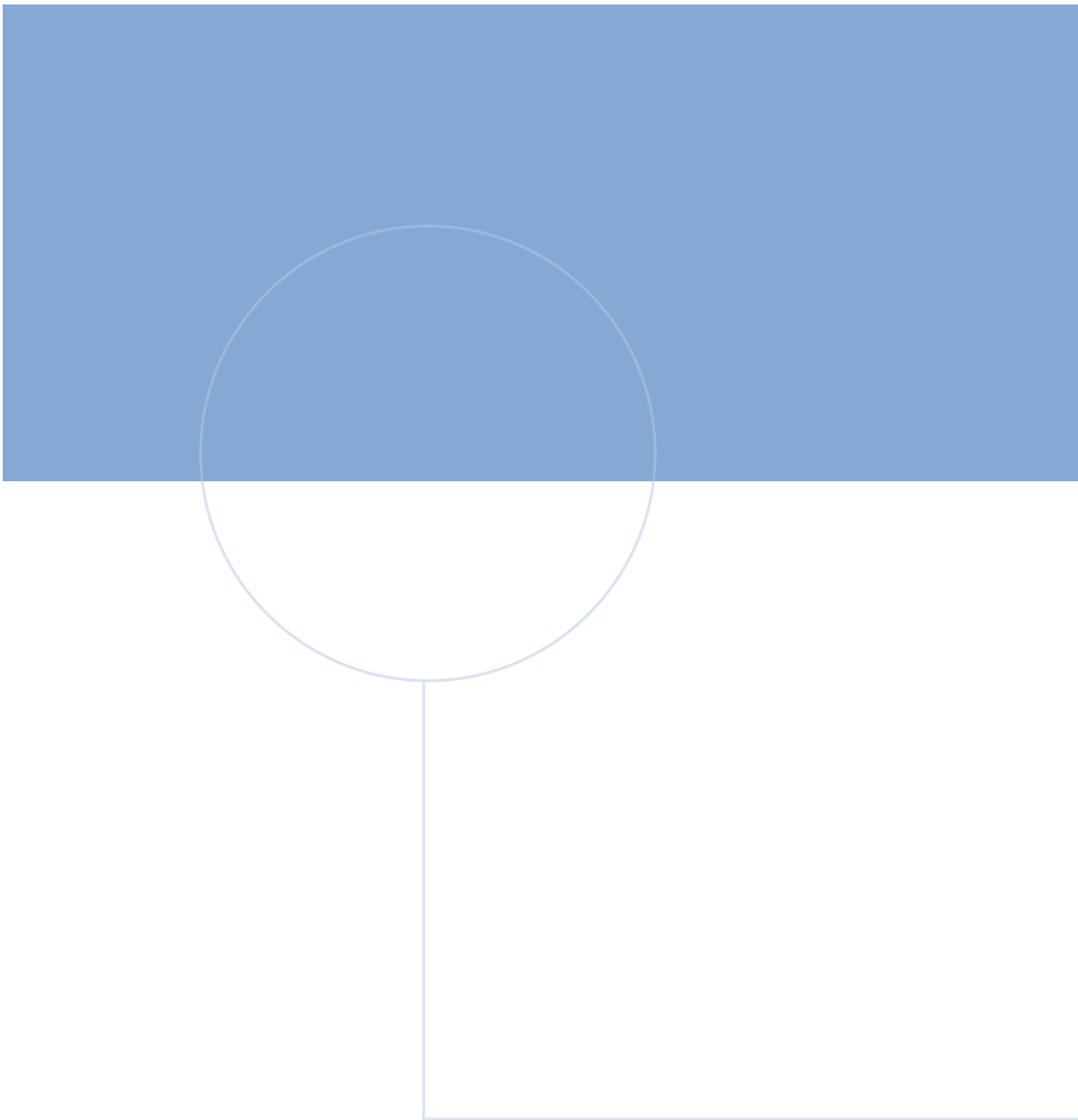
The steps of BizDevOps:	**W3C Committees - developing guidelines in each category:**
Idea	Business Strategy, Product Management
UI/UX Design	UX Design
Plan	Business Strategy, Product Management
Code	Web Development
Build	
Test	
Release	
Deploy	Hosting, Infrastructure, Systems
Operate	
Monitor	
Feedback	Business Strategy, Product Management
Analyze	

Further analysis, identifying key actions for each category:

Codes:	Core Categories and Key Actions:	Comments related to action:
P	**Planning / Design:**	
	- Design for data efficiency (navigation, asset minimizing)	4
	- Plan for sustainable dev and ops (assign sustainability representative, estimate environmental impact, set sustainability budget)	3
	- Design for energy-saving on end devices (e.g dark mode)	2
C	**Coding techniques / tools / frameworks (General, Frontend, Backend)**	
	- Minify assets, HTML, CSS, JS	7
	- Use code inspection/review tools, to optimize code quality and efficiency	6
	- Optimize browser caching / caching techniques	6
	- Efficient database queries	6
	- Encourage to follow W3C Sustainability Guidelines	
O	**Operation**	
	- Use automated quality control tools	8
	- Limit number of deployment-builds	5
	- Choose sustainable partners / hosting providers	4
M	**Management/Business/Strategy**	
	- Build knowledge and culture. Prioritize education on sustainable practices	8
	- Corporate focus on sustainability. Especially in large companies. Driving the change. Others will follow.	8
	- Visualize status / progress on metrics (e.g page load times / page weight) and goals	5

Renaming core categories, aligning with BizDevOps

	The phases of BizDevOps:	Key Actions:	Comments related to action:
Sus		- Build knowledge and culture. Prioritize education on sustainable practices	8
		- Corporate focus on sustainability. Especially in large companies. Driving the change. Others will follow.	8
Biz	Feedback	- Visualize status / progress on metrics (e.g page load times / page weight) and goals	5
	Analyze		
	Idea		
	UI/UX Design	- Design for data efficiency (navigation, asset minimizing)	4
		- Design for energy-saving on end devices (e.g dark mode)	2
	Plan	- Plan for sustainable dev and ops (assign sustainability representative, estimate environmental impact, set sustainability budget)	3
		- Choose sustainable partners / hosting providers	4
Dev	Code	- Minify assets, HTML, CSS, JS	7
		- Optimize browser caching / caching techniques	6
		- Efficient database queries	6
		- Encourage to follow W3C Sustainability Guidelines	1
	Build		
	Test	- Use code inspection/review tools, to optimize code quality and efficiency	6
	Release		
Ops	Deploy	- Limit number of deployment-builds	5
	Operate	- Use automated quality control tools	8
	Monitor		



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