Go ahead to Sustainable Interactive Systems

Practical Implementation and Evaluation the Elements of Green Coding and Resource-saving Design on an Existing Web Page

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Abstract. This publication introduced the practical elaboration to Sustainable Interactive Systems. Due to the constantly growing energy consumption of digital applications and their contribution to global CO_2 emissions, the sustainable design of web pages represents a major challenge and great possibilities.

Using an existing web page as an example, three elements of the sustainable design were implemented and evaluated - the database structure was adapted according to the principles of *Green Coding* (1), the use of media assets was optimized through picture format (2) and color selection was reprogrammed to dark mode for more efficient energy consumption of the display (3) according to *Resource-saving Design*. For example, through the optimization of picture format achieved a saving of over 99 % of file size - from the existing size of 12.4 MB to improved size of 0,024 MB.

The evaluation of improved state of the web page is based on measurement parameters such as loading times, data volume, server utilization of Central Processing Unit (CPU) and Random-Access Memory (RAM), supported by tools such as Website Carbon Calculator, Beacon, Google PageSpeed Insights, etc.

Furthermore, this publication presents the challenge between the flexibility of modern web design and the requirements for development of Sustainable Interactive Systems. The introduced procedure can be successfully transferred and improve the other Interactive Systems to more Sustainability.

Keywords: Sustainable Interactive Systems, Resource-saving Design, Green Coding.

S. Moebs et al. (eds.), *Proceedings of the FIREtalk Conference - Research on FIRE! (research-on-fire 2025)*,
Advances in Social Science, Education and Humanities Research 1018,
https://doi.org/10.2991/978-94-6239-705-7_9

1 Introduction and Related Work

1.1 Subject of the Investigation

In today's digital world, web pages are a central part of everyday life. With their diverse range of applications, they enable communication, trade, and information exchange worldwide in real time. In addition, web pages are becoming increasingly important due to the trend towards web applications, as the traditional way of local program installation is being used less. However, web pages, in addition to the opportunities already mentioned, also have negative impacts on people and especially on the environment, above all the increase in global energy consumption. Information and communication technologies, to which websites belong, also use resources over the entire life cycle, starting with production, through usage, and finally up to disposal (see Lange & Clasen, 2025, p. 4). In the last ten years, the energy consumption of data centers has doubled (see IBM, 2023). According to an infographic from Statista, the Internet alone causes an electricity consumption of 13 terawatt hours per year in Germany and was therefore in sixth place in 2020 in terms of its share of global CO_2 emissions. Furthermore, this source shows that Internet usage has steadily increased since 2014, so a further increase in the future can be assumed (see Statista, 2023). Due to these developments and the share in global electricity consumption as well as CO_2 emissions, optimizing websites regarding energy consumption is essential. Digital sustainability means creating and using digital resources in such a way that future generations are not limited (see Beyer, 2023, p. 4). Such sustainable development makes an important contribution to keeping global warming below 1.5°C, as decided in the Paris Climate Agreement in 2015 (see European Council, 2025).

For this investigation, the website of Delivery Breakfast (http://delivery-breakfast.projekt.dhbw-heidenheim.de/) was chosen as the object of analysis. The website was developed in 2024 as part of the student project "Project Development of a Database Application." This dynamic, framework-based website serves as an example of a modern web application, which was developed as part of a project at DHBW Heidenheim. The website of the fictional company Delivery Breakfast is an online shop for ordering individually composed breakfasts. Due to the many dynamic contents, graphics, and interactive elements, the homepage consumes a large amount of energy and thus offers great potential for improvement according to the principles of Green Coding. In addition, within the project framework, full access to the frontend, backend, and the implemented database already exists, so that the existing coding can be evaluated and optimized. These individual components of the website are each operated in a separate Docker container on the server, which are duplicated and modified for the optimization.

1.2 Approaches for Sustainable Interactive Systems

Two Approaches for Sustainable Interactive Systems were used in the presented work – the Green Coding and the Resource-saving Design.

Green Coding. Green Coding is an environmentally friendly programming practice that tries to minimize energy consumption during the processing of code lines and thus reduce greenhouse gas emissions (see IBM, 2023). The use of resource-saving technologies and a conscious selection of programming languages are also core topics of sustainable software development (see Wirtschaft Digital Baden-Württemberg, 2023). Green Coding belongs to the overarching concept of Green Computing, which tries to reduce the ecological footprint of technology. This area includes production lines of companies, data centers, as well as everyday business processes (see IBM, 2023).

Green Coding is based on four main pillars, which aim to minimize the energy consumption and environmental impact of software:

- green architecture,
- green logic,
- green methodology and
- green platforms.

Green architecture focuses on the efficient use of hardware. This includes, on the one hand, the optimization of the software structure to use the available resources in the best way. In addition, mechanisms are implemented that automatically switch off unused components to avoid unnecessary energy consumption. Green logic deals with the actual code optimization. Unnecessary instructions are to be avoided, resource-saving data formats should be chosen, and more efficient data structures used. By combining different levels, energy consumption can also be reduced. Green methodology relies on sustainable software development processes. Agile development models are preferred because they allow an early detection of inefficient code elements. Thus, these can already be changed during the project. Slim methods that can be reused in other software projects are also important. The last pillar is the green platform, which considers the infrastructure. Here, the aim is to use the server capacities optimally so that no unnecessary resources are wasted. A low workload is often the result of oversized planning, which is why a balanced ratio between existing infrastructure and actual use is the goal (see Wirtschaft Digital Baden-Württemberg, 2023).

Resource-saving Design includes strategies and technics for reducing data usage, data storage and data transfer for digital products and systems. Follow sixth aspects can be examined:

1. data availability;
2. hardware ability to software-updates;
3. shorter User Journey;
4. embedded media content;
5. picture format and
6. colors selection.

Less data availability needs less resources, for example water and energy for servers. Through hardware ability to software-updates the devices can be used longer and the expenses for production, and transportation of new hardware and devices are not caused. If the users have a shorter User Journey with web application, they directly reduce CO2 emissions. It is important here to test the User Journey with all stakeholders adequately. The embedded media content strongly influenced the date usage – which data added value for our digital product? The Hero-Section videos are used for more attention and need to be preloaded without knowledge to user interest. Depending on picture format can the efficient format as WebP in comparison to JPEG without loss of quality save of data usage. Also, colors selection as dark mode minimizes the energy consumption of displays. On OLED devices, the display of dark areas usually leads to a reduction in energy demand. However, under realistic usage conditions, the savings can decrease, for example, if user behavior such as increased screen brightness in dark mode partly cancels out the effect (see Purdue University 2022; BBC R&D 2025).

1.3 Proceedings of Practical Elaboration

At the beginning, analysis tools and different adjusting screws for an improvement of the website are worked out from the literature. In the next step, by means of the developed analysis tools, a determination of the actual state takes place. Based on the actual state, improvements are worked out, which are implemented in an optimized homepage version. These improvements were evaluated by support of the analysis tools. Through the same framework conditions, on the one hand comparability, and on the other hand also the reproducibility of the results is ensured. The changes to the object of investigation took place under the requirement of user-friendliness as well as the functionality of the web pages do not experience impairments.

2 Implementation and Evaluation of Improvements

2.1 Elements of Sustainable Design

Three selected elements of sustainable design were implemented and evaluated – the database structure was adapted according to the principles of Green Coding (1), the use of media assets was optimized by picture format (2), and color selection was reprogrammed to dark mode for more efficient energy consumption of the display (3), according to Resource-saving Design.

1. Data structure adjustment by green architecture: As part of the adjustment, the sizes of the single data fields were optimized so that they need less storage space. This way, the existing infrastructure, especially storage, can be used more efficiently without limiting the user.

2. Optimization of media content means formatting pictures into the WebP format, which is perfect for the use case of a homepage. Through changing the format and afterwards reducing the size of the picture files, the transferred data volume when the website is loaded is clearly reduced without the user seeing a loss in quality. With a smaller data volume, energy is saved both on the server and on the user device. The reason for this selection is the direct measurability of the actions, as reducing media content has a direct effect on loading time and transferred data volume. Also, the implementation effort is very low, because only the image path needs to be changed. This measure also shows that with small actions, without quality loss, a sustainable improvement for the website can be achieved.

3. Color selection is a way to design the website sustainably. Here, the dark mode of User Interface colors is chosen, especially for large contents of a homepage, to reduce the power consumption of the device. Especially on OLED screens, dark pixels save energy. This action was implemented because there is a direct, hardware-based power saving effect on many current end devices with OLED screens. Also, the implementation is easy through central CSS variables, and it is simple to maintain later.

To summarize, these three Elements of Sustainable Design were selected to show that the website can be made more sustainable without limiting the user experience.

2.2 Measurement Parameters of Improved State

For evaluation, different indicators are used, which show both the technical performance and the sustainability. The main measurement parameters are explained below.

Load time (1) describes the time needed to load the full subpage. A short load time reduces the waiting time for the user, but mainly the energy use of the devices. Changes to the website should always be in line with load time, to keep the user's experience and reduce energy use. For this, the open-source library tool Selenium WebDriver is used, which allows automatic interaction with a website. So, both frontend versions can be used in the same way, which makes sure the measurement of the load time is correct and the results can be compared (see Lyu et al., 2024, p.71). One example process is the configuration of a custom breakfast. With these steps, Selenium WebDriver is applied.

Data volume (2) describes the total amount of data that is transferred when the page is loaded (see Duden, n.d.). A smaller data volume has positive effects on the energy use of the server as well as the client device. Especially for mobile devices, energy can be saved, and the usage time can be increased (see Kern, n.d., p. 967). Beyer says a limit of maximum 2 MB per page load should be targeted to reach a resource-saving website. This limit can be reached by optimizing image formats or reducing CSS and JavaScript code (see Beyer, 2023, p. 20). The measurement is done with the tools cAdvisor, Prometheus and Grafana. cAdvisor monitors the four Docker containers, where the backends of the two websites and the two databases run. The monitoring works live and collects metrics like CPU usage and memory usage. With Prometheus, the data are collected and saved, so they can also be used later. Grafana visualizes the collected data as dashboards and makes it easier to analyze the data (see Malhotra et al., 2024, p. 6047).

Server utilization (3) describes the usage of the server during a request. This includes the Central Processing Unit (CPU) load and memory usage. High usage leads to high energy use (see Lyu et al., 2024, p. 71).

Online tools like the Website Carbon Calculator from Wholegrain Digital, Beacon from Aline or PageSpeed Insights from Google offer ways to analyze websites based on the content that must be loaded (see Beyer, 2023, p. 40). Beacon and the Website Carbon Calculator generate a produced CO2 value for loading the website. So, inefficient transfers or storage operations can be found and optimized. But it must be said that a deep analysis in such tools and the exact calculation cannot always be fully understood.

Another factor for energy use is the server (4) that hosts the website. Here, the energy balance of the hosting provider can give more details about the energy use (see Lyu et al., 2024, p. 71). Sustainable hosting of the webserver is affected by the location and the power consumption. If the website runs on a single server at a known location, these factors can be checked. This is not so easy for Content Delivery Networks, which store data on servers all over the world (see Beyer, 2023, p. 18f.). The goal is not only to reduce unnecessary energy use, but also to use hosting services that use only renewable energy, called green hosting (see Karyotakis & Antonopoulos, 2021, p. 4). Also, the data center should not be in a place with water shortage, because water cooling of computers needs a lot of water (see Lange & Clasen, 2025, p. 6).

Table 1. Measurement Parameters of Improved State.

Number	Parameter	Measure tools
1	Load time	Selenium WebDriver
2	Data volume	cAdvisor, Prometheus & Grafana
3	Server utilization	cAdvisor, Prometheus, Grafana, Carbon Calculator [17], Beacon [18] & PageSpeed Insights [19]
4	Server hosting	Energy balance of hosting provider

These measurement metrics showed an objective target-actual comparison for every change to the web pages to determine its impact. The selection of these metrics is based on the goal to achieve comparable results and to uncover technical weaknesses. The combined use of Website Carbon Calculator, Google PageSpeed Insights, Selenium, Grafana, storage and CPU usage, and data transfer volume enables a well-founded analysis of the ecological effects and resource utilization.

2.3 Comparison of Evaluated Parameters

The before–after comparison in Table 2 illustrates that the implemented measures led to measurable improvements in the examined parameters. The optimization of the database architecture resulted in a more efficient usage of storage space, while the conversion of pictures into resource-saving formats significantly reduced the data volume per page view. In addition, the introduction of dark mode provides further potential for reducing energy consumption, particularly on OLED-based devices. Together, these measures ensure shorter load times, lower CPU and memory load on the server, and thereby contribute to a more sustainable website operation.

By server hosting there are no improvements necessary currently. The ongoing hosting platform of web pages by Hetzner offers green hosting.

Table 2. Before-After (Original -> Improved) Comparison

Nr.	Parameter	Value	Original	Improved
1	Load time	Seconds	250	60
2	Data volume	MB	12,4	0,024
3a	Server utilization of CPU	%	Backend 0,265 Frontend 0,139	Backend 0,231 Frontend 0,0143
3b	Server Utilization of RAM	MB	214	5,59
3c	Server utilization		Website Carbon Calculator 69,92	Website Carbon Calculator 22,54
4	Server hosting		Hetzner (100% green energy, etc.)	

Following Fig.1 and Fig.2 deepens this analysis by comparing the energy-related impact of white mode and dark mode for selected subpages of the website. While the differences vary depending on the displayed content, the measurements confirm that dark mode generally achieves lower energy consumption without negatively affecting usability. This underlines the importance of design decisions in sustainable web development, as even visual aspects such as color schemes can directly influence technical and ecological performance indicators.

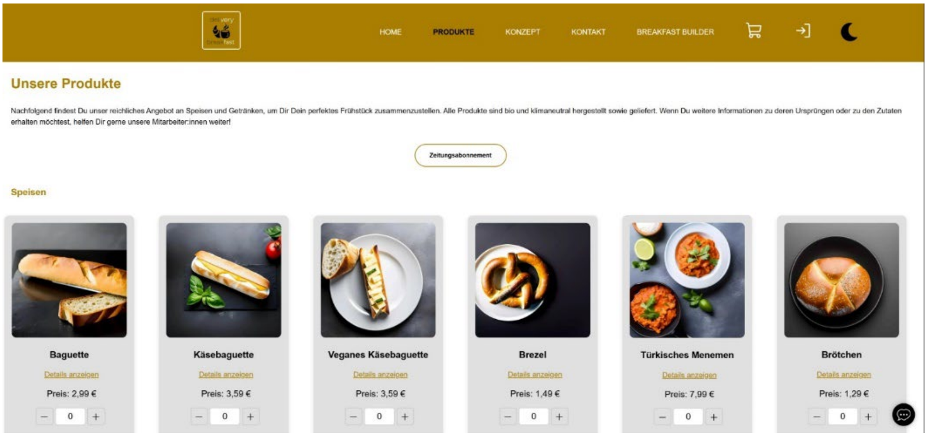

Fig. 1. A screenshot of existing web pages.

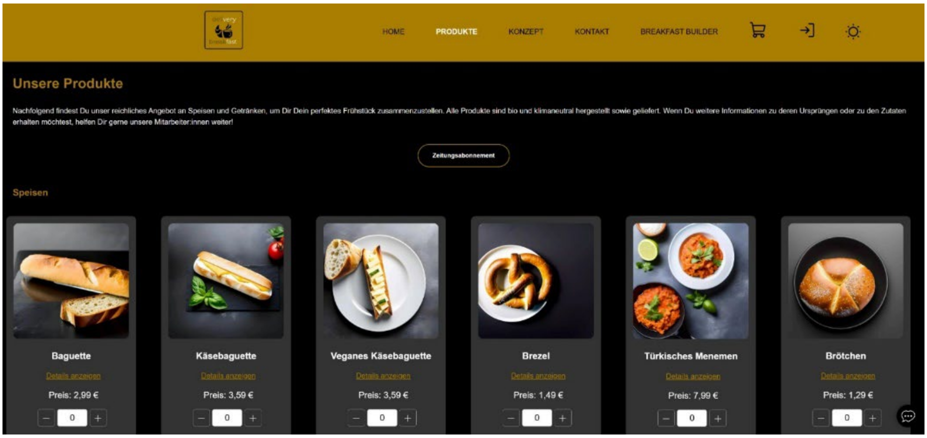

Fig. 2. A screenshot of improved web pages in *dark mode*.

3 Towards Recommendation to Sustainable Interactive Systems

3.1 Overview of Results

The results show that the presented measures together form an effective strategy to reduce energy consumption and optimize performance. At the same time, they raise new questions: While image optimization provides clear and measurable improvements in network usage, the actual effect of dark mode depends strongly on the hardware. Increased backend workload could also indicate that there is further potential for optimization in server-side processing. In addition, the analysis of external test tools shows that there is no standardized method for calculating CO_2 savings and that results vary greatly. While the internal test is a valuable way for detailed analysis, it should be further developed in the future to simulate load conditions and user interactions more realistically. This would allow a more accurate assessment of how optimizations work under real conditions and how performance and energy consumption change during practical use.

The methodological approach of this analysis shows some strengths but also weaknesses. A key advantage is the combination of external measurement tools and internal performance tests, which enables a differentiated view of the optimization effects. At the same time, however, the investigation focuses strongly on synthetic tests under fixed conditions. The tested scenarios do not reflect realistic usage patterns with varying load, so it cannot be clearly determined how the improvements behave in a live environment with high frequency of use. Also, possible interactions between the optimization measures are only considered in isolation, without testing them in a dynamic environment. Therefore, further investigation should include long-term tests and the effects under real operating conditions to enable a more reliable assessment of the actual effects.

Implementing these measures leads to a significant improvement in the technical and ecological key figures of the website. Loading times become shorter, which improves user experience. At the same time, energy consumption is reduced because less data is processed and transferred. The dark mode lowers power usage, especially on OLED displays, while more efficient image formats contribute to more resource-saving data transfer. The adjustments in the database architecture optimize memory usage and enable faster processing of queries.

3.2 Challenges

The so-called dark mode is increasingly implemented as an alternative display form in digital applications. Advantages mainly result from improved readability in low light conditions and potential energy savings on devices with OLED displays. On the other hand, there are limitations regarding readability in bright environments and increased requirements for consistent design of color contrasts.

Also, when optimizing database structures by green architecture, there is a conflict between increasing efficiency and possible loss of function. Especially the reduction of

VARCHAR fields can save memory and improve performance for queries. In databases with large tables and extensive indexing, this measure can lead to measurable efficiency gains. However, it must be considered that reducing the maximum allowed field length carries the risk of data loss due to cut-off inputs. Furthermore, later adjustments usually require structural changes, which are time-consuming in terms of migration and testing.

A conflict of objectives arises in the reduction of image sizes. A significant reduction of image files leads to lower storage and bandwidth requirements and has a positive effect on loading times and thus on the User Experience. Especially in mobile contexts, these effects are a decisive advantage. At the same time, there is a risk of significant loss of quality. While reduction can guarantee technical efficiency, the perceived content quality can be heavily affected.

4 Discussion

The analysis of the three main optimization features – data structure by green architecture, Dark Mode, pictures format optimization by WebP, and colors selection by dark mode – shows that a single measure alone is not enough, but that only the combination brings a sustainable improvement. Image optimization shows the clearest effects on network usage, by reducing the average receiving rate in the front end from 1.94 KiB/s to 174 B/s. At the same time, the transferred data amount in the network drops from 1.48 MiB/s to 24.1 KiB/s. This reduction of data volume not only eases the servers but also has a positive effect on loading times and energy consumption of the devices. While this is a direct technical improvement, it is still open whether the savings achieved lead to the expected reduction of CO_2 emissions or if there are external factors that make the effect stronger or weaker.

5 Conclusion

This paper analyzed the optimization of a website according to the principles of Green Coding and Resource-saving Design to reduce the energy consumption and the environmental impact of digital applications. The constantly increasing energy demand of web pages leads to Sustainable Web Development becoming more important. To develop resource-saving solutions, it is necessary to analyze existing digital structures and improve them in a targeted way. The goal of this paper is to increase the sustainability of the website through technical changes without reducing its functionality or User Experience.

For the analysis of the starting situation, both internal measurement methods and external evaluation tools were used. Various technical aspects of the website are considered, including loading times, data volume, CPU and memory usage, as well as server efficiency. Based on the results of this analysis, targeted optimization measures are derived and implemented. The focus is on three main measures: the introduction of dark mode to reduce energy consumption on modern displays, the optimization of image formats to decrease data volume, and an adjustment of the database structures for more efficient resource usage. These measures can be applied together or individually to other web page optimizations.

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