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DOCUMENTATION

POTENTIALS OF GREEN CODING: PERSPECTIVES ON IMPLEMENTATION

SEPTEMBER 2023

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ABOUT THE PROJECT

Software, as a basis of the Internet, has significant influence on energy consumption, energy efficiency, and the useful life of hardware, and, therefore, on the energy and resource consumption of the Internet. Software quality is characterized in particular by efficient programming. The basic idea of Green Coding is, therefore, not new. But the importance of this approach has increased significantly in recent years. Despite its great importance, general regulations or even recommendations for sustainable software are still in their infancy.

Green Coding methods seem to be promising approaches that have become increasingly popular among experts and researchers. Nevertheless, there is a lack of awareness regarding the interconnectedness of the technical, economic, and environmental factors within the Green Coding discourse. This project is a cooperation between the German Informatics Society, the Berlin University of Applied Sciences and the Environmental Campus Birkenfeld of the Trier University of Applied Sciences. The project team seeks to adopt a comprehensive approach that recognizes and carefully considers these interdependencies. The aim is to address various stakeholder groups which are crucial for promoting environmentally friendly practices in web development, including software developers, Internet-related companies, and students pursuing computer science degrees in universities. The research goal is threefold:

- To determine what concepts of Green Coding exist in theory and how they can be put into practice.
- To analyze which concepts of environmentally friendly software engineering are already in use in the software industry.
- To identify ways in which Green Coding concepts can be integrated into the curricula of existing study programs.

This publication summarizes the findings from our stakeholder workshop and online survey used to analyze which concepts of environmentally friendly software engineering are already in use in the software industry.

Umwelt-Campus Birkenfeld | Hochschule Trier

htw Hochschule für Technik und Wirtschaft Berlin
University of Applied Sciences

GI GERMAN INFORMATICS SOCIETY

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SUMMARY

The Information and Communication Technology (ICT) Industry has experienced substantial growth over the past few decades. With this growth, there has been an increased focus on the carbon footprint associated with the ICT sector and the importance of resource- and energy-efficient software.

However, various interpretations and terminologies surrounding Green Coding and sustainable software exist, leading to challenges in effectively implementing specific measures during the development process and communicating their strategic advantages and disadvantages. It is important to note that about half of the surveyed software companies consider Green Coding a strategic goal, but only 18% actively measure the environmental impact of their software. This discrepancy makes it difficult to accurately assess the true impact of their implementations, making it one of the major challenges.

To prevent the phenomenon of greenwashing in the software development process, where resource and energy efficiency are recognized as selling points without substantial environmental benefits, it is crucial to widely disseminate and provide accessible methods and tools for measuring the environmental impact of software products, including their energy consumption, while at the same time establishing standardized units of measurement. In order to get an insight from persons working in the field, a survey was conducted. Participants believe that there is untapped potential in the development process, particularly in terms of educating software engineers, implementing official guidelines and requirements, as well as increasing visibility and raising awareness.

By addressing these aspects, the industry can strive towards a more environmentally conscious approach, fostering genuine sustainability and maximizing the positive impact of software development on the environment.

SURVEY RESULTS

SAMPLE AND PROCEDURE

Respondents were recruited through the partners' extensive networks and through posts on the project website, LinkedIn as well as Twitter. The target audience were people working in software developing companies. The survey was available in English. All data was collected between December 12, 2022, and February 6, 2023. Ninety people gave their consent to participate in the study. Responses were recorded from ten different countries (Table 1), although the majority of respondents were from Germany (79%). 24 people chose not to answer.

Country	#	%
Germany	52	78.79%
Switzerland	2	3.03%
Austria	2	3.03%
Romania	2	3.03%
United States	2	3.03%
Working remotely	1	1.52%
India	1	1.52%
Ireland	1	1.52%
Spain	1	1.52%
United Kingdom	1	1.52%
Brazil	1	1.52%

Table 1: Demographic Information

About 80% of participants had a technical role in their company (Figure 2) and all had varying levels of expertise with half having more than ten years of work experience (56%) as shown in Figure 1.

Approximately, how many years have you been working in the software industry?

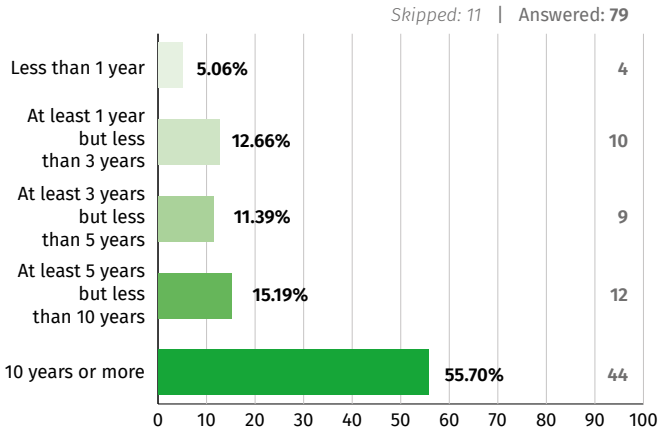

Figure 1

Do you have a technical role in the software development process?

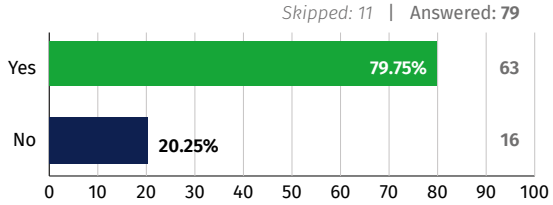

Figure 2

The represented companies varied greatly in their number of employees (Figure 3) and the type of application they built, with cloud (71%), web (63%) and machine learning (39%) being the most popular (Figure 4).

What is the approximate total number of employees?

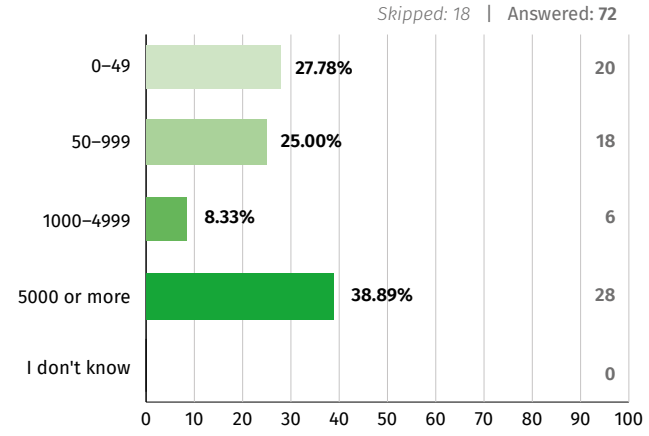

Figure 3

What types of applications do you primarily build?

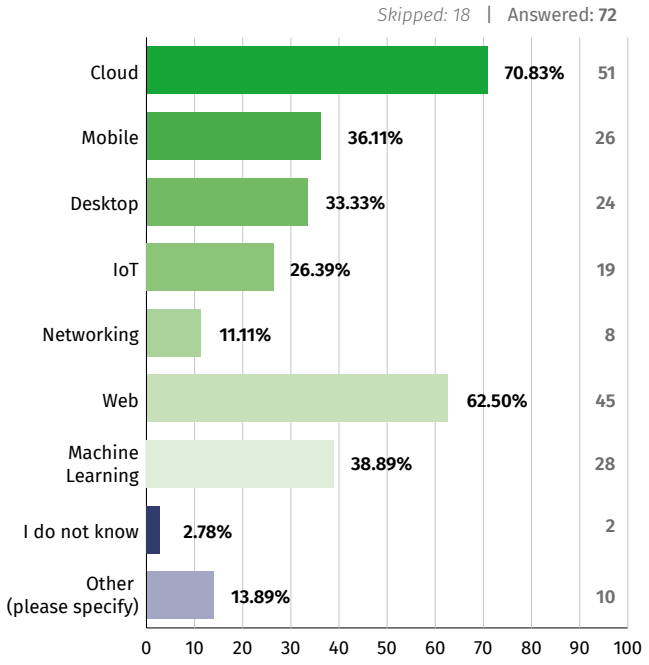

Figure 4

RESULTS

1 AWARENESS

To what extent do you agree with the following statement: Enough is being done to promote and publicize the topic of sustainable software development.

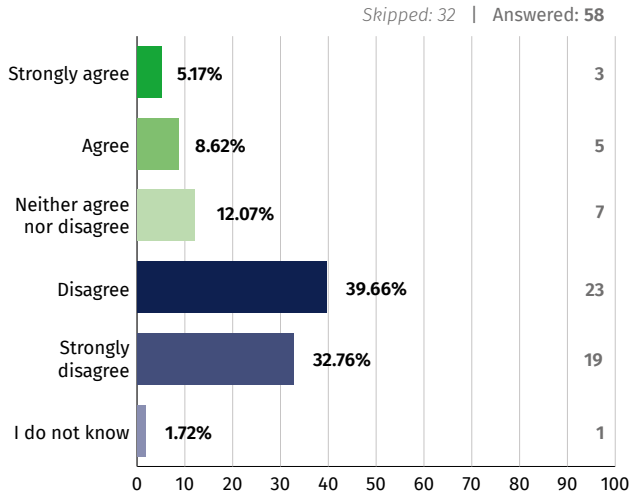

Figure 5

Green Coding is widely seen as not being promoted enough. When asked if sustainable software development was appropriately promoted, 72% of respondents answered "disagree" or "strongly disagree" (Figure 5). No qualitative data was gathered on which stakeholders are seen as responsible for facilitating these activities of raising awareness and transferring knowledge.

2 CORPORATE STRATEGIES

Is it a strategic goal to reduce the negative environmental effects of your own software products?

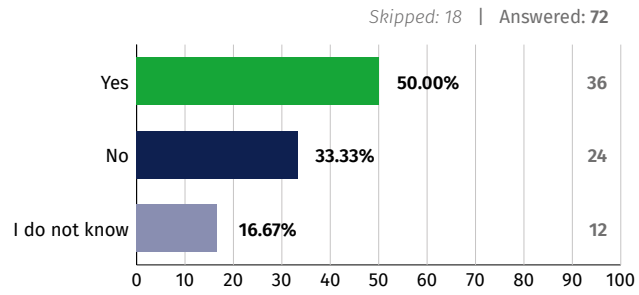

Figure 6

Half of the survey participants stated that the software-producing company they lead or are employed at has a strategically aims to reduce negative environmental effects of their software products (Figure 6). A reason for this could be shifts in policy, with related European regulatory activities currently being implemented or planned. In May of 2022, the EU Commission published a roadmap on the Ecodesign and Energy Labelling Working Plan of 2022–2024. These policies regulate the environmental performance of energy-related products, such as the energy and water consumption, emission levels, and overall material efficiency of an end product.[1] While this regulatory plan does not specifically state code, but is rather focused on end products, the ubiquity of software in many products, appliances, and services plays a role.

To what extent do you agree with the following statement: Our company does enough to reduce the environmental impact of our software.

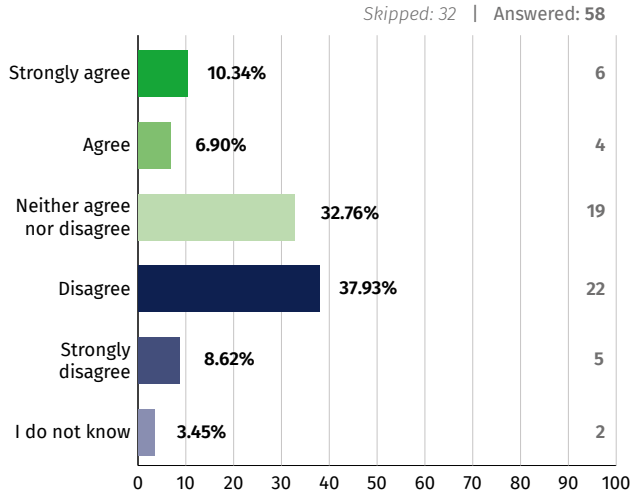

Figure 7

To what extent do you agree with the following statement: Other companies do enough to reduce the environmental impact of their software.

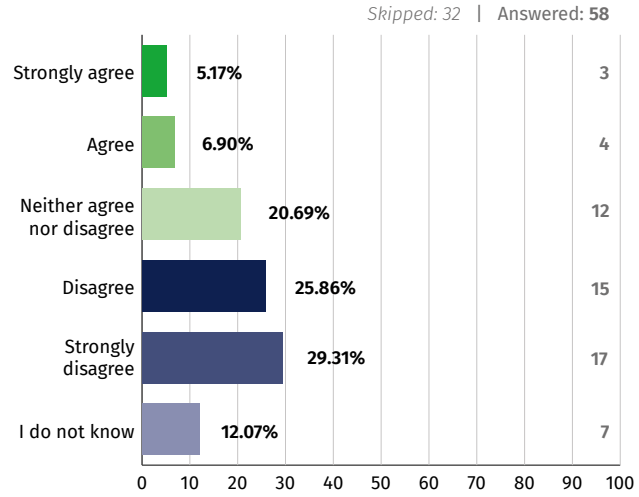

Figure 8

However, perspective was provided on the extent to which respondents felt that software-producing companies are in fact doing enough to reduce their environmental impact. Among the respondents, 17% strongly agree or agree that their respective companies, which they lead or work at, are putting in enough effort, whereas 47% disagree (Figure 7).

Only 12% of respondents are in agreement that other software companies, where they do not work, are doing enough.

In addition, 55% disagree that, in general, other companies are taking enough or the right steps to lower their negative environmental impact (Figure 8).

[1] https://energy.ec.europa.eu/publications/ecodesign-and-energy-labelling-working-plan-2022-2024_en

3 SOFTWARE DEVELOPMENT STRATEGIES

Does your company use Green Coding strategies to reduce the environmental impact of your software?

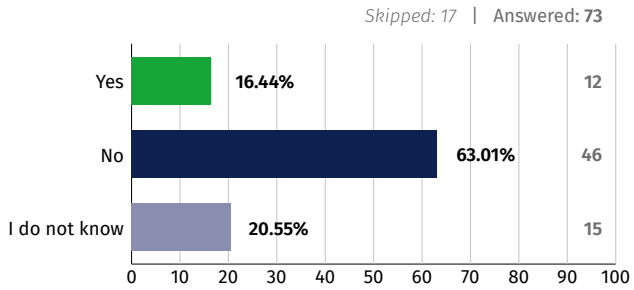

Figure 9

The rate of software-producing companies that have already consciously integrated Green Coding strategies is relatively low at less than 17% (Figure 9). The respondents, who indicated that they use Green Coding strategies gave an insight into the strategies they use (Figure 10).

What role do the following sustainable software criteria play in your company's software development process?

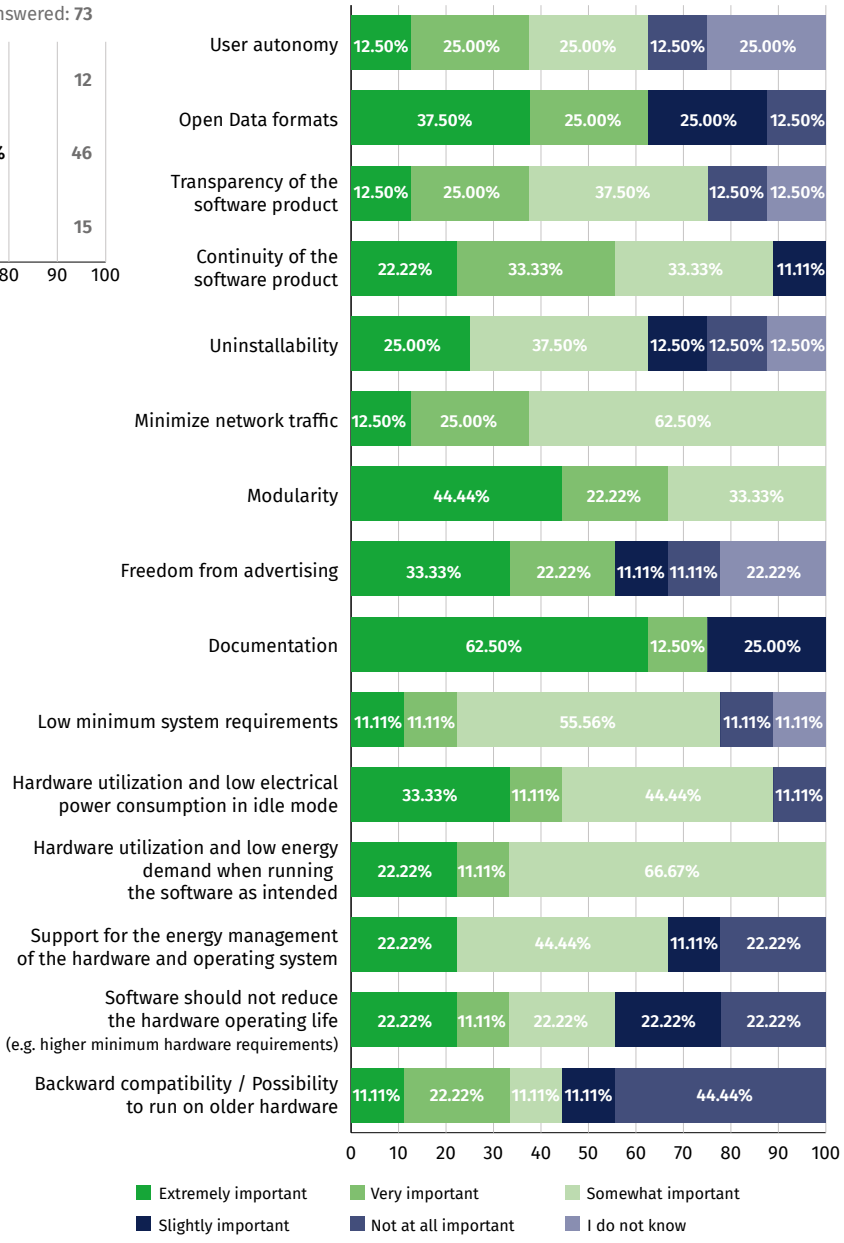

Figure 10

The criteria included in the survey, taken from the requirements defining the eco-label 'Blauer Engel' (Blue Angel) for resource- and energy-efficient software products, are intended to enable the development of sustainable software. These criteria are not concrete methods or strategies, but rather define aspects of software with a high impact on the sustainability of a software product. Each criterion could be fulfilled by a number of concrete methods or strategies (e.g., methods identified by RQ.1 in the literature report).

"It should be noted that the Blue Angel is not solely concerned with environmental sustainability. As a result, not all criteria have a clear impact on the environmental dimension of software sustainability (e.g., the use of open data formats does not necessarily result in a more environmentally sustainable product). Evaluating a piece of software in development against the Blue Angel criteria and making efforts to optimize [...] them could be an effective way to produce sustainable software. Process models and measurement protocols, intended to assess and promote sustainability in software engineering, have been published and may provide a foundation for developing sustainable software.

High diversity in software products (use cases, tech-stack, system environment, required interfaces) dictates that concrete measures, such as Green Coding strategies and methods identified in the literature report, should be implemented based on current research, system knowledge, and technology-stack expertise. This requires sustainability awareness and competency from developers."

(Sebastian Weber, Umwelt-Campus Birkenfeld, 2023)

Those who answered that no strategies were used gave reasons for not (yet) integrating Green Coding in their processes (Figure 11).

Why do you think the topic of Green Coding plays a subordinate or no role in the development of your software?

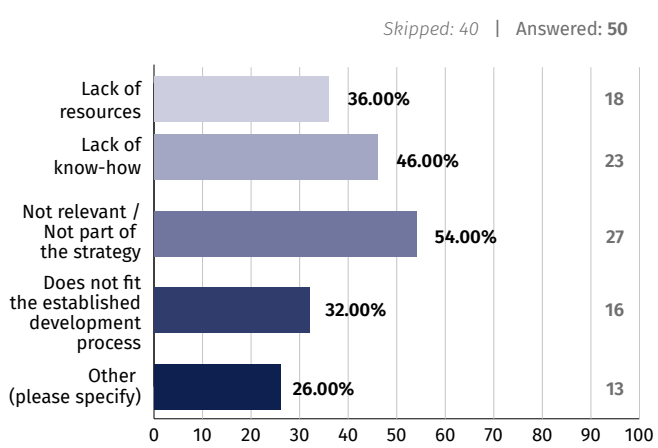

Figure 11

Respondents also had the option of providing qualitative answers to elaborate on their reasons for nonuse. These can be broadly summarized as follows:

- lack of time and resources for software engineers to implement new processes;
- lack of interest in the topic from corporate representatives, customers and/or software engineers resulting in slow or lack of implementation;
- greener software is not (yet) a strong enough selling point;
- the topic is too new or just now becoming relevant.

However, it was noted several times that on the level of corporate strategy, Green Coding has recently been increasingly recognized. Several respondents also pointed out that energy efficiency in itself can be a motivator as the subsequent reduction in costs can be significant, for example for providers of cloud services and software as a service.

"Of the respondents, 46 % stated that Green Coding plays a subordinate role in the software engineering process due to a lack of know-how.
For the purposeful and effective implementation of sustainable software engineering into educational programs, it must be considered which institutions have a large influence on the knowledge of future software developers. This can potentially be determined by the evaluation of the Formal Education Levels, which were published in 2022 by Statista.

The focus was [...] put on the implementation of curricula in institutes of higher education. A search of the current distribution of Green Coding programs, courses, or modules revealed that only 10 universities, 8 in the EU and two in the US, offer modules on Green Coding. However, it should be noted that modules and courses are usually announced internally through campus management systems, so the number may vary. Nevertheless, in relation to the current number of higher education institutions offering software development, this is only a fraction of what is needed for the sustainable development of the industry. One can speak of a 'lack of education'."

(Dennis Junger, HTW Berlin, 2023)

4 UNUSED POTENTIAL

"Algorithms and software that ultimately control servers play a key role in determining the energy consumption of digital infrastructures and applications. I see this as an important building block for greater sustainability in digitization, which can lead to significant CO_2 savings. Using AI applications as an example, the Massachusetts Institute of Technology has calculated that optimal programming can result in potential savings of up to 20% in hardware energy consumption. The Hasso Plattner Institute for Software Systems Engineering, which is also a member of our association, already has many exciting approaches for passing on this knowledge in research and teaching to the next generation of developers and IT decision-makers. We urgently need these minds in tech companies."[2]

(Alexander Rabe, managing director at eco – Association of the Internet Industry, 2022, translated by the authors).

The fact that there is room for improvement is reflected in the answers of the respondents: When asked if they see unused potential for a more sustainable development process, 75% of respondents agreed (Figure 12).

In your opinion, is there unused potential for a more sustainable development process?

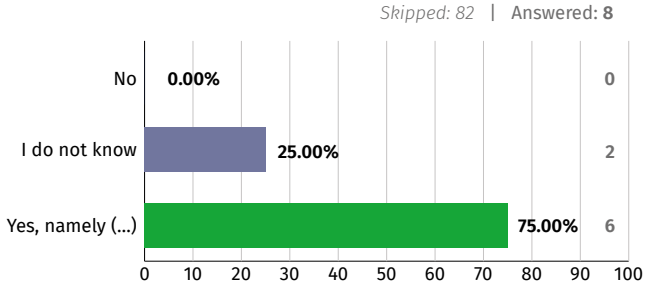

Figure 12

They named different levels of potential intervention or need for change, which pertain to both technical and strategic roles in companies, as well as standards and norms:

- "More focus on education in terms of software programming efficiency, algorithmic efficiency and better tailored framework usage."
- "Energy consumption needs to be a requirement in the development process like test coverage or security."
- "Many applications have potential but [Green Coding] needs to be made visible and understandable to management."

Does your company measure the environmental impact of its software?

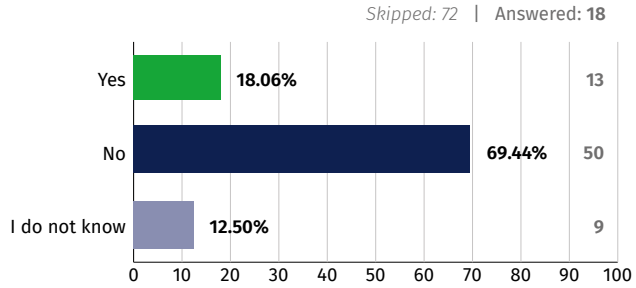

Figure 13

One limiting factor to both strategic progress and technical advancement of Green Coding in software-producing companies seems to be a lack of data, as 70% of survey participants answered that their company does not measure environmental impact of software products (Figure 13).

During the Potentials of Green Coding industry workshop (see next page), participants discussed the lack of data and identified the resulting problem to provide evidence-based arguments for the implementation of Green Coding in companies.

[2] Full Interview can be found here: https://gi.de/en/aktuelles/meldungen/detail/three-questions-for-alexander-rabe.

INDUSTRY WORKSHOP

WHAT YOU CAN'T MEASURE, YOU CAN'T MANAGE. TO MEASURE IS TO KNOW.

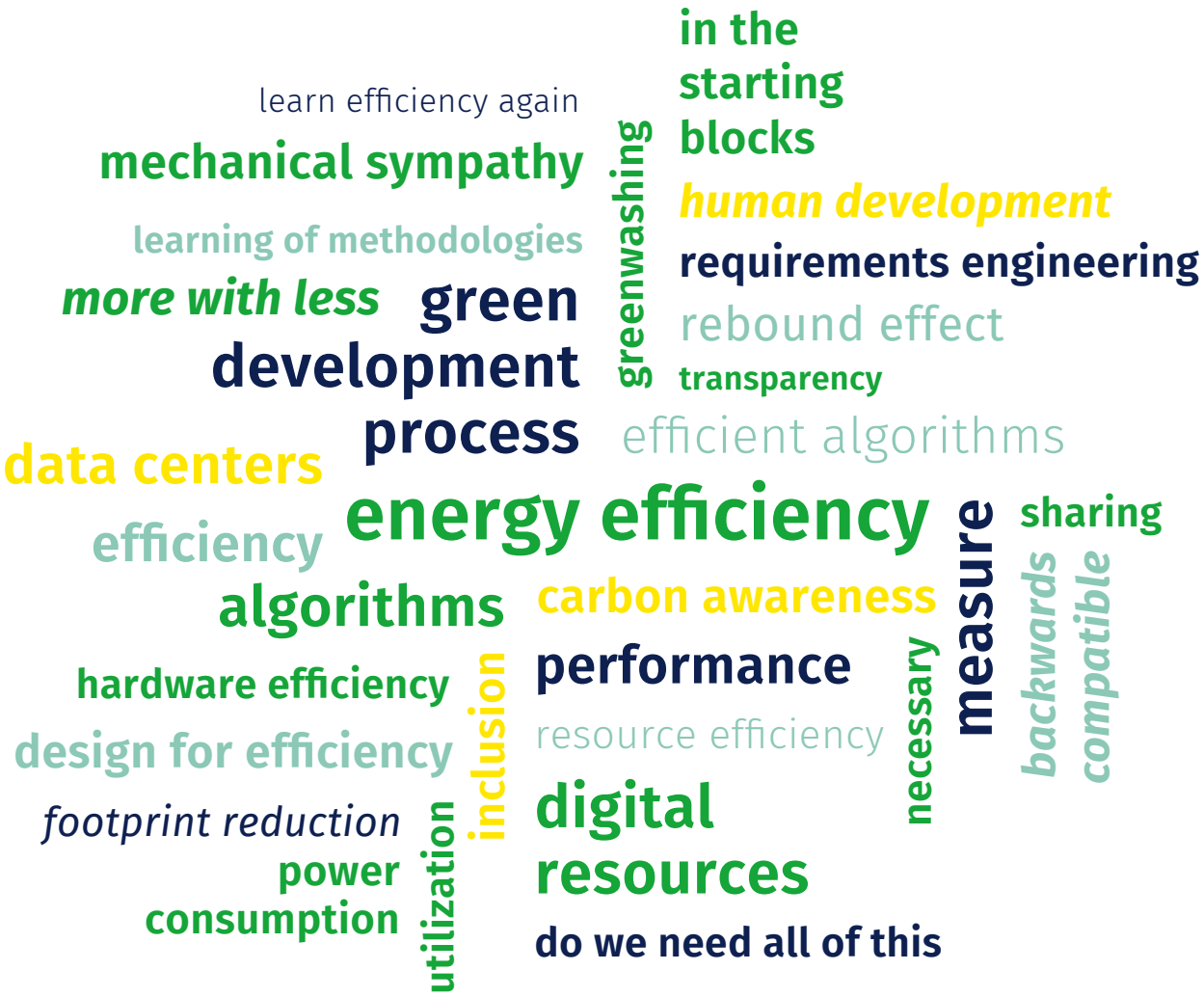

Figure 14: Participants were asked for their association with the term Green Coding

Image 1: Michelle Thorne during her presentation.

The need to raise awareness, more readily available and transparent data, as well as a mutual understanding of units of measurement and frameworks pertaining to Green Coding are some of the key takeaways from the industry workshop held on March 7, 2023. During the workshop, representatives from academia, companies such as DATEV, Google and adesso, and civil society organizations met in Berlin to discuss challenges and conditions for the implementation of sustainability goals in software.

Three inputs outlining the current state of research on sustainable software development constituted the first part of the workshop. Prof. Dr. Stefan Naumann (Umwelt-Campus Birkenfeld) presented possible categories for classifying software as sustainable. Dennis Junger (HTW Berlin) then introduced possibilities for integrating sustainability into the education and training of computer scientists and software engineers. Worldwide, there are currently only a few implemented examples in higher education. In the third presentation, Michelle Thorne (Green Web Foundation) outlined the role of sustainable energy resources and the strategies already available to make the Internet greener.

The recordings of the inputs can be found here: *https://www.youtube.com/playlist?list=PLYcO8AUs-4DaFuwtrviynAmqQfkSdXQn9A.*

The subsequent Q&A gave participants a chance to discuss the topics with the researchers. During the discussion it became clear that the experiences and challenges associated with the implementation of sustainable software practices are multifaceted and differ vastly – not only between companies but also within a company depending on the individual's role in the firm.

When asked what role Green Coding plays in their company, the majority of participants indicated that the sustainability of their software is a topic of discussion but Green Coding strategies are not currently being implemented or followed strategically (Figure 15). The most common challenges reported are a general lack of awareness and knowledge of how sustainable coding can affect a software's energy consumption, lack of transparent and reliable data when it comes to measuring the carbon footprint of software, as well as a missing measurement standard to use. Further, the need for a structural and ultimately a political shift became apparent. As of now, regulatory plans are focusing on the environmental effects of hardware and there are no rules and regulations that ensure a mindful consumption of resources when it comes to software.

What role has Green Coding in your company and are the strategies for it already implemented?

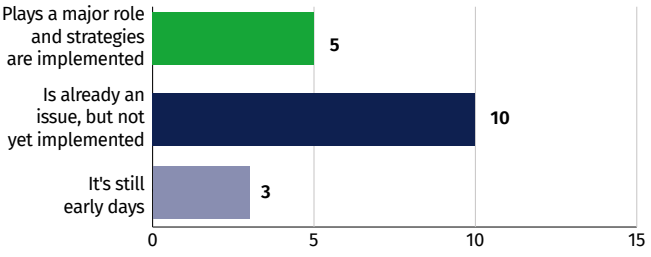

Figure 15

In the subsequent workshop, participants dove deeper into the specific challenges within their companies and the digital industry in general. In a lively exchange, they expressed what was needed and what they wished for in order to ensure that a green transformation can become reality in the software industry.

WORKSHOP RESULTS

In the industry workshop in March 2023, participants collaborated on the following questions:

- What are hindrances regarding the implementation of Green Coding?
- What could be success factors for wide-spread implementation?

In several rounds of discussion, participants gathered various ideas and compared their experiences. Throughout the exchange, it became apparent that measurability and units of measurement are a core concern. The ideas on these aspects are, therefore, grouped separately.

MEASURABILITY AND DATA

- As carbon awareness is one level of green(er) software, the current energy consumption of specific software products needs to be measured and this information needs to be analyzed before making changes that otherwise might not address the issue at hand.
- As long as the energy consumed is carbon-based, sustainability potentials cannot be fully accessed.

> "For green electricity to be available in sufficient quantities and at cost effective conditions for the operation of digital infrastructures and corresponding applications, the expansion of renewable energies must first be massively promoted. We have been calling attention to these shortcomings for many years. At the European level, we have also joined the Climate Neutral Data Center Pact. We are working with the EU to develop specifications and units of measurement that are intended to create a uniform European framework for operators of digital infrastructures in the future. For us and our members, making the operation of data centers as efficient as possible has always been a top priority. And with success: The energy consumption per workload has decreased twelvefold in the past ten years, which is an impressive increase in efficiency."[3]
>
> *(Alexander Rabe, managing director at eco – Association of the Internet Industry, 2022, translated by the authors)*

[3] Full Interview can be found here: https://gi.de/en/aktuelles/meldungen/detail/three-questions-for-alexander-rabe.

- Methods and tools for measuring environmental impact of software products, of which energy consumption is one aspect, need to be made widely known and available, and units of measurement should become standardized. However, while not everything can be measured exactly or the data might sometimes be inconclusive, it is better to introduce imperfect measuring systems than none at all. As Prof. Dr. Naumann says: "Better roughly right than precisely wrong".
- Currently, the granularity and units of measurement (for example, regarding amounts of data, CPU, electricity use) are not entirely clear and different companies may also measure differently, if at all.
- Comparability can be a challenge even with standardized units of measurement. For many software products within a company or use case, the environmental impact could only be compared to a former version as no exact sustainable alternative is usually produced.
- Comparing different use scenarios and features might be a starting point if they can be sufficiently identified and isolated.
- Once performance measurements pertaining to sustainability factors have been put in place, they can become a regular part of the development process but need to be explicitly recognized as such.

CHALLENGES FOR THE IMPLEMENTATION OF GREEN CODING

GENERAL CHALLENGES

- There are different, sometimes diverging, interpretations and terminologies regarding Green Coding and sustainable software. This can make it challenging to effectively introduce specific measures in the development process and communicate their advantages and disadvantages on a strategic level.
- The quality and value of software development processes and products is often determined by key performance indicators (KPIs), such as development velocity or code stability, for which units of measurement are established. For sustainability aspects, such frameworks are not yet widely known. This led to the following questions during the workshop:
  - Are tools and units of measurement available and applicable for different use cases?
  - Can these sustainability KPIs be standardized, and can companies be convinced to report on them?
  - Can the effects that software engineering processes and specific software products have on the environment be precisely determined by life-cycle analyses or other methods?
  - What are practical consequences of a negative "sustainability score"? Should existing but unsustainable software products then be adapted accordingly?
- The trend of making "everything digital" may lead to more software being produced and used than is needed and, therefore, lead to the adverse sustainability impacts.
- A lack of regulation and political willingness leads to a variety of different standards while accountability is lacking.
- Green(er) software is not yet seen as a selling point for clients; therefore, it might not be seen as economically beneficial to adapt processes and software products accordingly.

SOFTWARE DEVELOPMENT PROCESSES

- A lack of educational opportunities on Green Coding and the consequential lack of know-how prevents its effective implementation, as there are not enough software engineers with the specific knowledge and skills needed, and educational programs are not yet standardized through curricula.
- If a top-down strategy is not in place, implementation of new measures and pressure from the technical roles in the company to become more sustainable may not be welcome. In addition, it may be unclear, where the responsibility for the topic lies. This is particularly the case when staff changes occur in companies where the advocacy for and implementation of Green Coding has been driven by individuals, rather than being firmly established within the company policy
- Green(er) Coding is sometimes broadly seen as costly and labor intensive, while potential gains through increased efficiency and marketable sustainable products are hardly ever considered.
- If sustainability indicators are not part of the standard review and developer key performance indicators, motivation is low to consider them in the process.
- Development tools and frameworks might need to be re-examined and evaluated before determining if they lead to more sustainable outcomes. Information on the best technical solution or units of measurement for such decision-making are currently not universally available.

SUCCESS FACTORS FOR GREEN CODING

GENERAL

- Allowing for creative exploration of options, as well as data and information gathering before implementing new steps in the development process.
- Quantifiable sustainability aspects should be treated as standard units of measurement for quality evaluation of software.
- Awareness needs to be raised regarding the climate crisis and the impact of digital technologies, both in managerial and technical roles in all companies. Only if the urgency of implementing Green Coding is understood on a large scale, will effective changes be made.
- Stable networks need to be established, which allow for sharing of best practices and evidence-based recommendations on how to implement Green Coding strategies in different fields.
- Advocacy and exchange with relevant policymakers needs to be sought out to further regulatory approaches and increase clarity for all stakeholders. Through policy action, public awareness can increase, and sustainable software can be regarded with the same urgency as hardware.
- Alternatives for current business models can and should be openly discussed.

SOFTWARE DEVELOPMENT PROCESSES

- Incentives for development teams need to be put in place to produce greener software. These can raise motivation and could be implemented similarly to game days. A game day simulates a failure or event to test systems, processes, and team responses.
- The role of Green DevOps should be implemented and strengthened, as they report on sustainability indicators of a product, whereas other roles mostly report on traditional KPIs such as time of deployment or code stability.
- Sustainability discussions and reviews should be introduced to project management frameworks and sprints, as they are currently not a regular module.
- If good solutions and tweaks to development processes have been identified for a team, a product, or a company, they need to be documented and formalized in order to be used consistently.
- Open-source projects and accessible libraries for Green Coding strategies and frameworks increase choice and diversity of approaches for all kinds of software.
- Software architectures and the synchronicity of work tasks need to be evaluated: Not everything needs to be running at the same time. Decreasing parallel processes might have direct sustainability effects.

Representatives from the following companies were present during the workshop: *msg, MaiborrnWolff, adesso, sandstorm, Bosch, DATEV, Syngenio, Lufthansa, Deutsche Bahn, Google, Arvato Systems.*

OUTLOOK

Considering its potential, there is a growing expectation that Green Coding will become a standard practice in the software development industry. An increasing number of developers and organizations are prioritizing their energy-efficient coding techniques and make conscious efforts to minimize the carbon footprint of their applications. While the path forward is not set in stone, several key aspects and trends are likely to emerge.

Developers will likely place a greater emphasis on optimizing code to reduce energy consumption. This involves writing more efficient algorithms, minimizing resource usage, and eliminating unnecessary computations. Techniques such as code profiling and performance testing will likely be widely employed to identify energy-intensive code segments and optimize them for efficiency.

Cloud computing is poised to play a significant role in enabling energy-efficient software development. Cloud service providers are encouraged to invest in green infrastructure, relying on renewable energy sources to power their data centers. Green Coding will have a significant impact on data centers and infrastructure. Data center operators are encouraged to minimize energy consumption. Moreover, the use of renewable energy sources to power data centers will become increasingly prevalent. Developers can use cloud services to their advantage to dynamically scale applications, optimizing resource allocation and reducing energy waste from idle servers.

Green Coding will go beyond code optimization and permeate throughout the software development lifecycle. This will entail adopting sustainable development practices, such as effective use of version control systems to minimize code duplication, embracing agile methods to reduce rework and waste, and integrating automated testing and deployment processes to enhance efficiency.

The industry can develop standardized guidelines and certifications for Green Coding practices but are called to closely cooperate with educational institutions and standardization bodies to ensure transferability and academic soundness. These standards will establish benchmarks for energy efficiency, resource optimization, and sustainability in software development.

At the same time, regulators and public authorities are expected to evaluate the role of sustainable software and determine public measures and regulations that help foster sustainability and provide clarity on indicators, rights, and responsibilities.

As sustainability gains global prominence, awareness surrounding Green Coding will surge. Collaboration and knowledge sharing among developers, organizations, and environmental experts can accelerate the adoption of eco-friendly coding practices.

In conclusion, the future of Green Coding holds promise. However, the realization of its full potential hinges on the collective efforts of developers, organizations, and the technology industry as a whole, as well as regulators and policy bodies. By working together, we can make significant strides in reducing the environmental impact of software while promoting sustainability and a greener future.

GREEN/}
CODING

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