Labelling Sustainable Software Products and Websites: Ideas, Approaches, and Challenges

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***Abstract*—*The awareness for software as an important player regarding the energy consumption caused by ICT steadily increased in the past years. The impact of software on the energy consumption is also more and more accepted by the research community under the umbrella of sustainability in general. Nevertheless, the end user is still only slightly or not addressed in the research activities regarding the whole energy consumption of software over its complete lifecycle. Also other stakeholders, e.g. administrators, designers, developers etc., are not in the focus of creating awareness for the aforementioned topics. In this contribution, we therefore focus on ideas, approaches, and challenges in developing a general-purpose labelling process for green and sustainable software products and websites. At first we provide a literature roundup, followed by the elaboration of requirements for the creation of a sustainability label for software products in general based on already existing and new approaches. On a first attempt, we furthermore concentrate on a labelling process for sustainable as well as green websites and sum up with a discussion followed by an outlook on our future work.*

Keywords—green software; web engineering; eco-label

I. Introduction And Motivation

The research activities in the area of green and sustainable software and its engineering are steadily increasing. The topic resulted in many contributions, journals, conferences, and workshops. Two major focus areas in the aforementioned research field are based on the questions how ICT can encourage sustainability ("sustainable by ICT") and how ICT itself can be more sustainable ("sustainable in ICT"). In this context software is also an issue. It is, next to hardware, substantially responsible for the energy consumption caused by ICT as well as the positive impact of software in the context of sustainability in general. Hence, focusing on software aspects can be expressed by the terms "sustainable by software" and "sustainable in software". We will dwell on corresponding definitions in Section 3A.

For us the field of "sustainable by software" also covers the field of "green by software" since green spots on the environmental pillar of sustainability. Hence, when we talk about sustainable by software, green by software is also included in that. It is the same for green or rather sustainable (in) software. If one will concentrate just on the environmental part, the term "green" explicitly points that out.

However, especially the attention of the energy consumption of software could be much higher in order to identify and implement additional potentials. In particular, the end user is only slightly or not addressed within these research activities. Indeed, its influence is high and should not be underestimated. "Up to 90 % of the energy used by ICT hardware can be attributed to the application software running on it" [16]. This statement of the GHG Protocol is only one example showing the importance of the usage phase and therefore the user in the context of the energy consumption of software and the overall ICT. Above, e.g. Zhang et al. [41] deal with the role of users regarding energy consumption focusing on mobile devices.

Although the end user is in the focus of our work addressing all of the stakeholders, namely administrators, designers, developers, authors, and end users, makes sense to round up these activities. Here, possibilities how to create awareness upon the impact of software onto a sustainable development needs to be found. In our paper, we will focus on a possibility to address users and developers.

One possibility to include users and developers in the activities around sustainable software is the development of a label for this kind of software. There could be a certification of software products in the sense of quality labels and based on standardized criteria. A certification body like the environment agency or another similar control board could award the sustainable software product. In that way information on sustainability relevant aspects are spread and the transparency for sustainability aspects of ICT can be supported. This approach is successfully proved for other product categories, e.g. household appliances, organic products, and consumables. Within the ISO 14000 schema the International Organization for Standardization deals with environmental labels and declarations (ISO 14020 to 14025). Hence, a standardized certification process for sustainable software products should be laid on these declarations. In our paper we will not go into details of these documents because we focus on comparing existing approaches in sustainable software engineering. The standardization of the whole process is a vision of the future.

Our paper discusses requirements and existing as well as new approaches regarding a label for sustainable software products in order to point out the state of the research and next

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challenges in this context. The findings are mostly based on literature reviews, but also include new ideas. In addition to the general addressing of the challenges for labelling sustainable software products, the possibilities for a label for green websites are considered. Here, green web engineering [14] is seen as one specific part of sustainable software engineering. It bridges the field of web engineering and Green IT, especially focusing on the energy consumption of the web.

The paper is structured as follows: Section 2 looks at the related work and research activities regarding sustainable software. Section 3 goes into issues being relevant in creating a sustainability label, shows up existing approaches, and compares them to be able to come up with new approaches. Section 4 and 5 concentrate on web engineering by presenting an approach for sustainable websites (Section 4) and afterwards having a closer look at green websites (Section 5). Section 6 states open questions and points of discussion. At last, Section 7 presents our conclusions including findings of our work and a short outlook for future work. Overall, the idea is to present the state of research as basis for further developments and to launch a further dealing with the topic, e.g. applying corresponding case studies.

II. Related Work

Based on the definition of sustainable software [13] and its advancements (e.g. [7, 31, 33]), the research results comprise models and approaches specifying the topic of sustainable software development and analyzing the energy and resource consumption of software [8, 23, 24, 26]. Related to the software product itself there are approaches for criteria and metrics (e.g. [6, 7, 31]). The evaluation and implementation of the criteria and metrics in practical projects is missing so far. Additionally, energy consumption measurements are an issue in the current research area. Here, for example, approaches of measuring the energy consumption of databases [9], virtual machines [25], and mobile applications [40] exist. Another issue in energy efficient software development is the programming style and its relation to the resulting energy consumption (e.g. [28, 32]). A lack of current research approaches is the missing connection to real software usage. Thus, a next step is to develop usage scenarios in order to find suitable metrics and estimate the induced resource consumption over the whole life cycle of software products. This can result in classification for sustainable software products.

Beside the different research activities and because of the relevance of the usage phase for the resulting energy consumption induced by software [16] the end user should be involved into the activities of sustainable software. One possibility to do so is to visualize the energy consumption or rather the environmental impact. Here, some prototypes are already published: the browser plugin "(Green) Power Indicator" shows if the server a website is hosted on is operated with renewable energies [27]. Wilke et al. [39] present a marking system for the energy consumption of smartphone apps. Further green web initiatives exist online, e.g. co2stats[1], Greenanalytics[2], Greenfox[3].

III. Relevant Aspects and Approaches Regarding Sustainable Software

A. Definition

At first, in order to create a common understanding of the term "sustainable software product", a clarification and distinction will be elaborated in the following. So far, one can find a few versions of definitions in the literature that are mainly representing the results of projects with slightly different foci ([7, 13, 29, 31, 33]). At next, we will evaluate these definitions and bring them together to build a basis for a future standardization and potential labelling for sustainable software products.

Dick et al. [13] published the first definitions for sustainable software and sustainable software engineering in 2010. Hence, the following definitions provide the basis for later published definitions: "***Sustainable Software*** *is software, whose impacts on economy, society, human beings, and environment that result from development, deployment, and usage of the software are minimal and/or which have a positive effect on sustainable development.*" [13] and "***Sustainable Software Engineering*** *is the art of defining and developing software products in a way so that the negative and positive impacts on sustainability that result and/or are expected to result from the software product over its whole lifecycle are continuously assessed, documented, and optimized.*" [13]

Regarding the software product, Calero et al. [7], Penzenstadler et al. [31], and Schmidt et al. [33] come out with additional definitions that include but slightly change the basic aspects of Dick et al. [13]. Whereas Dick et al. name explicitly the impacts on economy, Schmidt et al. drop this and point out the conservation of the nature and social fairness by laying emphasis on the "integrative" sustainability. Above that, they replace the "and/or" by "and" to underline the importance of long-term positive effects of the software product. The "by" aspect, that is to be seen as an addition in the definitions of Dick et al. and Schmidt et al., is focalized by Penzenstadler et al. They come out with "Software Engineering for Sustainability (SE4S)" and talk about the process that is supported by sustainable software. They highlight the purpose of the software product to support sustainability and reduce the characterization of the software itself to energy efficiency in the definition. However, Calero et al. see "sustainable" itself as a characterization for software products. They postulate to add sustainability as an additional non-functional requirement for software products. Hilty et al. [20] also follow this approach. Hence, sustainability can be seen as a quality aspect that improves a software product.

[1] http://www.co2stats.com/faq.php

[2] http://greenanalytics.ca/

[3] http://greencodelab.fr/en/content/greenfox-firefox-addon-to-measure-your-browser-consumption

All authors agree on the fact that sustainable software engineering is a precondition to develop a sustainable software product. Next to the definition by Dick et al., Calero et al. published a definition for sustainable software development. This definition gives priority to a software development "in which resource use aims to meet product software needs" [7] and ecological sustainability. In contrast to Dick et al., they do not mention life cycle assessment aspects at all.

Summarizing, the different definitions have the following aspects in common: (1) environmental and resource protection as well as (2) supporting sustainable development including the three pillars of sustainability, but setting priorities. Overall, it is negligible on which one of the sustainability models the definition is based on since the overall aim is the same. A holistic view is important.

B. Identification of Criteria

If there is a common understanding for sustainable software products, the next step is to identify criteria. Here, the state of research is similar to the definition part. Many contributions deal with possible criteria, that can be brought together to find a common basis [2–4, 7, 8, 10, 22, 31, 35]. Indeed, an evaluation of the proposed criteria in the field is missing. Following, we will give an overview of the current status in theoretical elaborations and show how the approaches can fit together. By showing possibilities how to bring the criteria together and analyzing overlaps and specifics we will show up possibilities for structuring the criteria. The review will be laid on the criteria presented in the Quality Model for Green and Sustainable Software [22], complemented by results of newer publications. Hence, we will not describe the criteria in detail but reference corresponding publications instead. The aim is to create a basis for drawing up evaluations of identified criteria. The collection does not list must-have criteria for sustainable software products but presents possibilities that need to be further developed.

In order to structure criteria for sustainable software products, mainly the following approaches can be found: (1) structuring based on the three pillars of sustainability, (2) mapping the criteria onto the life cycle of software products [4, 26] and/or onto (3) first-, second- and third-order effects [26], and (4) dividing them into categories like (a) common quality criteria, directly related and indirectly related criteria [22], (b) process and product aspects [29] or (c) resource-oriented and well-being oriented sustainability indicators [6]. In many cases the approaches present criteria completed by sub criteria or sub characteristics [7, 22, 35]. Beyond that, the criteria are connected with either "sustainable in ICT" or "sustainable by ICT" [26, 29]. They have either a positive or a negative impact on sustainable development.

	Life cycle phase the criteria is to be considered	
Main Criteria	**Development Phase**	**Usage Phase**
Efficiency defines how software behaves when it comes to saving resources and avoiding waste.	• Energy Efficiency • Number of Methods • Framework Entropy • Resource Optimization • Memory Usage	• Peripheral Intensity • Memory Usage • Hardware Utilization • CPU Intensity • Hardware Management • Runtime Efficiency • Idleness • Energy Efficiency • Performance (Efficiency) • Functionality • Reflectivity
Resource-oriented Feasibility considers how environmental aspects of a sustainable development are supported.	• Energy Consumption • Carbon Footprint • Waste • Travel • Infrastructure • Energy Type	• Energy Consumption • Energy Type • Carbon Footprint • Effectiveness
Well-being oriented Feasibility considers how social aspects of a sustainable development are supported.	• Supportability • Organizations Surroundings • Accessibility • Satisfaction	• Usability • Accessibility • Sociality • Satisfaction • Dependability • Beauty • Supportability • Freedom of Risk
Perdurability can be defined as the degree to which a software product can be modified, adapted and reused in order to perform specified functions under specified conditions for a long period of time.	• Reusability • Functional Suitability • Reduction • Modularity • Testability • Analysability • Modifiability	• Obsolescence • Functional Types • Reliability • Adaptability • Fit for Purpose • Reduction • Maintainability • Context Coverage • Portability • Maturity • Availability • Fault tolerance • Recoverability • Installability • Replaceability

Figure 1 Draft of identified criteria for sustainable software products mapping to Efficiency, Feasibility & Perdurability

For the purpose of finding criteria for sustainable software products on which a label can be based on, a summary of the specific criteria that can be found in the given literature is necessary. Summing up the different categorizations for sustainability criteria we come to three keywords that cover all of the known approaches: *Efficiency*, *Feasibility*, and *Perdurability*. In order to specify these, *Feasibility* is separated into *resource-oriented Feasibility* focusing on environmental impacts and *well-being oriented Feasibility* focusing on social impacts. These main criteria for sustainable software have to be specified in greater detail by dedicating suitable criteria. By rating the sub criteria the degree of fulfillment of the main criteria can be analyzed.

In Figure 1 we mapped the found criteria to the proposed main criteria and separated them by the development and the usage phase. The results of analyzing approaches for sustainability criteria are not summed up or ordered to show the existing criteria flood. Moreover, the presented collection is not intended to be exhaustive.

It is obvious that the complexity to sort them is quite high and it is a big challenge to come to a standardization in this context. Hence, in order to specify the main criteria by finding corresponding sub criteria it is important to be sure about the aim and the focus of the label. The specification might also depend on the kind of software that should be labelled. As soon as these questions are answered and thus the general set-up for a label is defined, an award guideline has to be developed based on the criteria.

C. Form of Representation

By analyzing currently existing eco-labels we found a lot of representations: (1) standardized labels including required by law vs. voluntary, (2) differentiated vs. specific vs. multidimensional, and (3) many designs for labels for (a) products, (b) producers, and (c) branches. Moving forward in creating more and more labels leads to an information explosion users cannot handle. Hence, not only the definition and criteria need to be clear but also the form of presenting these product characterizations. In order to create a recognition value the following approaches for forms of representation of the sustainability of software products will be described with international examples of eco-labels.

1. Quality classes similar to the Green Power Indicator[4]: One has to define general quality criteria that have to be fulfilled by all of the sustainable software products. Additionally to that, the product can be ranked higher if it meets more criteria than the basic ones. This grading can be presented by different colors, e.g. green, yellow, and red.
2. Presenting a statement for the labelling similar to the Blue Angel[5]: Here, the environmentally friendly aspect of the specific product, meaning the protective goal, is directly shown on the label, e.g. "protects humans and the environment".
3. Neutral label without presenting any grading or statement similar to the Energy Star[6] or the EU Ecolabel[7]: The label helps to identify sustainable software without giving any information about criteria.
4. Declaration of the average induced CO_2 emissions similar to the Carbon Footprint Label of UK Carbon Trust[8]: They differ between the Reduction CO_2 Label communicating the measurement of the carbon footprint and the commitment to reduce it on the one hand and the CO_2 Measured Label communicating just the first aspect. The consideration can also be expanded by all of the greenhouse gases resulting in a GHG footprint. Above, the footprint of the whole software development project or the footprint of the software product itself can be calculated. This form of representation might be a way to achieve transparency and awareness for sustainable software products, but it covers only one specific aspect of sustainability.
5. Declaration of the average induced energy consumption similar to the EnerGuide Label[9] of the Government of Canada: Instead of presenting the CO_2 emissions it labels and rates the energy consumption or energy efficiency of specific products. Indeed, this does not cover the whole aspects of sustainability either.
6. Combination of different forms of representation similar to the EU Energy Label[10]: It is a uniform label in all EU28 members that states and presents a rating of the energy efficiency of the product by classes mapping to colored arrows. Additionally, the energy class, the supplier's name or trademark and model identifier as well as the annual energy consumption are given. Pictograms highlight specific characteristics depending on the product that is labelled.

D. Target Groups

In order to analyze potentials for labelling sustainable software products, one has also to look after the target groups. Who can benefit from a label?

- *Developers* are interested in labels for libraries and tools like integrated development environments. They are also general interested in the criteria in order to consider them during the development.
- *Administrators* are interested in labels, which help them to distinguish between different software products with similar functionality. They also want to know differences, e.g. in energy efficiency of frameworks, runtime environments, and operating systems.
- *End Users* normally use a software product only on one computer / tablet / smartphone. They are interested in labels, which compare standard software like browsers, office software, etc. A label for custom software is not so relevant. They also might be interested in the question, how "green" a service or a website is.
- *Ecological activists* are interested in criteria for Green ICT and how a label might improve sustainable development.
- *ICT companies* are also interested in the criteria and want to know, how they can improve their products. They also want to increase their sales by labelling software.

These ideas for target groups can be interpreted as small starting points for a broad target group analysis being implemented after the general set-up for the label is available.

E. Stakeholders

Whereas the target groups comprise those who should be addressed in order to arouse their interests for the qualification, stakeholders are the ones without whose support the implementation of a qualification for sustainable software products would be pretty much impossible. Hence, both groups may overlap but follow different interests. Obviously, the individual persons in both groups are diverse by motivation, interests, personality, and initiative. Whereas the stakeholders are already interested in the specific field in general, the awareness of target groups for appropriate

[4] http://www.green-software-engineering.de/en/software/powerindicator.html

[5] https://www.blauer-engel.de/en/our-label-environment

[6] http://www.energystar.gov/

[7] http://ec.europa.eu/environment/ecolabel/

[8] http://www.carbontrust.com/client-services/footprinting/footprint-certification/carbon-footprint-label

[9] http://www.nrcan.gc.ca/energy/products/energuide/12523

[10] http://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficient-products

activities still needs to be created in most of the cases. However, it is important to consider stakeholders as well as target groups in developing a label for sustainable software products. The first one especially in order to push the development and the distribution of the label (and all the processes in there), the second one especially to bring awareness to it.

Regarding the identification of stakeholders Penzenstadtler et al. [30] present four approaches of identifying stakeholders for sustainability in software engineering. Herzog et al. [18] identified actors involved in Green IT innovations as they state that "actors can affect the whole life cycle of IT" [18]. In order to find out the stakeholders in our context (labelling sustainable software products) both findings can be combined: the generic list of sustainability stakeholders by Penzenstadtler et al. [30] is based on five different dimensions of sustainability (individual, social, environmental, economic, and technical), whereas the approach by Herzog et al. only goes into the three pillar theory of sustainability as we did. Hence the list can be adapted and mapped to the development of a certification program for software. The models of innovation presented by Herzog et al. should be integrated as well. Thus, ideas how to move on and push the labelling activities forward might be a result. Another important aspect is that the identification of stakeholders needs to be evaluated by mapping concrete case studies to the theoretical findings in order to make the consideration as complete as possible.

Just to come up with some ideas and clarify the stakeholder aspect in the context of labelling sustainable software product: First of all, we see the end user as the one who will gain information about sustainable software and its dimensions by presenting those aspects by a certification. Above, the company who is developing sustainable software product can make a name for herself being sustainable and can grant relief to their Corporate Social Responsibility. Indeed there are also those who are part of the software and sustainability activities and interpret a sustainability label as possibility to support and bring awareness to these activities.

Overall we go with the final statement by Penzenstadtler et al. [30]: "We are positive that successfully identifying the stakeholders for sustainability will help ensure that this objective receives the deserved attention." In our opinion this also holds true for the labelling process.

IV. Consideration on Sustainable Websites

After considering the comprehensive field of software, we will focus on websites in the following Sections 4 and 5 in order to reduce the complexity and present how the first step of breaking down the reference criteria to more concrete ones. Since web engineering can be seen as one specific part of software engineering, we will first reduce the domain by looking at websites instead of software products in general in the following section. The break down is not unmitigated and does not present a final solution.

The basis of a sustainable website (product) is web engineering (process of developing the product) that pays attention to sustainability aspects. Hence, before going into details, the question if the website itself or the whole web engineering process including the product website should be labelled needs to be clarified. In a first step of labelling sustainable websites, we will focus on the product. Here, it is possible to evaluate the website as a black box. The next step could be a comprehensive evaluation of the whole process including aspects like the energy consumption of the infrastructure used for developing the website and business trips, belonging to the development of a website and commuters of the development team.

Following the structure of Section 3, we will first present a definition for sustainable websites, followed by a suggestion for corresponding criteria and possible forms of representation.

A. Definition

A definition for sustainable websites should meet the identified aspects of sustainable software discussed in Section 2: environmental and resource protection as well as sustainable developments. Hence, the following definition based on [13] (see Section 5) is a first approach: *A **sustainable website** is a website that is optimized in terms of a sustainable development over its whole life cycle. Negative direct and indirect impacts on sustainable development are reduced, positive impacts on sustainable development are supported. The impacts should be monitored over all life cycle phases.*

The definition is a first step to create transparency by being a basis to build on and it might help to create awareness of the different stakeholders including administrators, designers, developers, authors, and end users [14]. All of them are an issue in the context of web engineering and should be addressed.

B. Criteria

Criteria on how to characterize a sustainable website help to label a sustainable website and to realize the definition presented above. In order to get a first impression of how one can decide if a website is sustainable, we sum up some criteria inspired by the criteria collection presented in Figure 1 and the cited literature. It is a first approach and needs to be further refined. The criteria for sustainable websites can be the basis for labelling websites. Overall, the different aspects can be classified as ecological, economic, and social criteria, based on the three pillars of sustainability. Some of the characteristics belong to more than one sustainability aspect. In order to find a connection to the criteria for sustainable software products and their engineering, we will match the criteria to *Efficiency*, *Feasibility*, and *Perdurability*.

The following set of criteria helps to evaluate the degree of fulfillment regarding the *Efficiency*, *Feasibility*, and *Perdurability* of a website. The following list is by no means complete and not intended to be so.

Efficiency "defines how software behaves when it comes to saving resources" [35]. In our opinion this is applicable to websites. The following criteria specify and evaluate the *Efficiency* aspect in the context of sustainable websites.

- *File Sizes*: The file sizes of the website content should be kept to a minimum, e.g. by compressing source

code and minimizing images. Recommendations for actions can be found in [14].

- *Number of Files*: The number of files should be kept to a minimum, e.g. by combining separated files.
- *Data Transfer*: The induced data transfer of the website should be kept to a minimum, e.g. by using caching. Recommendations for actions can be found in [14].

Feasibility considers how aspects of a sustainable development are supported [35]. As presented in Section 2 we differentiate between resource-oriented and well-being oriented criteria. *Resource-oriented Feasibility* can be specified and evaluated by the following criteria:

- *Energy Type*: The server hosting a sustainable website should be operated by renewable energy.
- *Energy Consumption*: The energy consumption should be continuously monitored and optimized during the life cycle of a website.
- *Energy Management Options*: The possibility to deactivate energy intensive content like animations should be given to the user. The user should be able to get the whole content of the website also without using the energy intensive functionalities.
- *Carbon Footprint*: The carbon footprint specifies the amount of CO_2 emissions caused by the website during its life cycle. It should be calculated and analyzed regularly in order to continuously reduce the induced emissions.

Well-being oriented Feasibility can be specified and evaluated by the following criteria:

- *Sustainability Support*: Sustainability support especially concerns the content of a website. The support is given if the website presents for example a community for sustainability relevant topics or a knowledge base with articles on how to save energy and resources etc. This criterion mainly goes for sustainability by websites.
- *Accessibility*: The website should meet the user's needs to give accessibility to as many users as possible. For example colors as well as font sizes should be adaptable. In this context, Web Content Accessibility Guidelines are developed through the W3C process [37].
- *Usability*: Features that enable a website to be user friendly should be integrated. Usability guidelines list specific criteria to check the usability of a website, e.g. the guidelines published by The Website Standard Association [38]. In order to keep the usability of a website on a high level usability tests should be applied regularly.

Perdurability can be defined as "the degree to which a software product can be modified, adapted and reused in order to perform specified functions under specified conditions for a long period of time." [8] Regarding websites the following criteria specify and evaluate the *Perdurability* aspect:

- *Maintainability*: The maintainability of a website should be kept as high as possible. That means that it is possible to analyze and change the files in an effective and efficient way. Here, having a well-structured and thorough documentation of the website makes sense. Different kinds of documentation should be created: guidelines for administrators and guidelines for authors. The guidelines can help to maintain the site in a sustainable way regarding the source code as well as the content.
- *Adaptability*: Adaptability belongs to aspects regarding user experience (1) as well as technical aspects (2). (1) In times of a huge amount of devices with various screen sizes, qualities, and usage scenarios, the website should be highly adaptable to meet the user's expectation. For example, the site should adapt itself spontaneously if the screen changes from portrait to landscape mode or from small screens to bigger ones. (2) Next to direct user interactions as social aspect technical configurations influence the environmental part. Here, e.g. reduced bandwidth or higher energy consumption of cellular networks for data transfer are issues. For example, images of the mobile version of a website can be smaller by default.
- *Reusability*: Reusability considers the aspect of using existing methods and code fragments of websites for different development projects. This gains importance both intern in a company and for cross-cutting projects in the World Wide Web, in other words it is more efficient to use the same methods for different websites as to create or rather load it again for each case.

Overall, there needs to be more research regarding social aspects of websites, web engineering or rather software engineering in general [21]. Johann et al. focus on equal opportunities and participation as social aspects. Economic aspects are even more important while including the whole web engineering process, the project, the organization developing the website, etc.

As a next step the criteria need to be evaluated from a practical view, means reviewing if and how a website is checkable by this criteria and how a corresponding checklist as well as recommendations for actions can look like. This will be the basis for award guidelines for a label.

C. Form of Representation

Nowadays, the term "sustainability" is used in different ways depending on the specific context. Hence, the complexity how to understand the term the right way is high whereas the traceability is not given for most of the stakeholders. In order to react to this development the information about sustainable software needs to be clear. Thus, a label presenting this specific characterization of a software product should be expressive. Here, a label like the

Blue Angel presenting the protective goal could be a good solution.

Thinking of a label for sustainable software there might be differentiated label versions informing about the sustainable aspect (social sustainability, ecological sustainability, and economic sustainability) that should be highlighted and is fulfilled most. In that way the user gets to know why and how the specific product is sustainable. Another possibility is to use this statement to figure out if the software product itself is sustainable (sustainable in software) or if it supports sustainable development (sustainable by software).

Above, a label with gradations seems to make sense for sustainable software products. So far, the development of sustainable software is just in the beginning and the different criteria might not be fulfilled completely. Different quality classes provide the opportunity to label a product that is sustainable in some aspects. Optimizations of the product arise as a result of progressing development of sustainable software engineering principles.

V. FOCUSING ON GREEN WEBSITES

Next to concentrating on a specific part of software products (here: websites), the complexity of creating a label for sustainable software products is additionally reduced by focusing on a specific sustainability aspect. Hence, we will have a more detailed look on possibilities of labelling green websites, meaning we will dwell on the ecological sustainability instead of including social and economic aspects additionally. The following consideration are based on our previous works. Focusing on websites corresponds to the results of Hilty et al. [20]. They point out that traditional websites or web-based applications could be suitable for labelling. In our paper, we will predominantly consider websites providing information in a static way and using standard web technologies like HTML, CSS, etc. Criteria for green web content management systems and web applications can be found in [12].

Corresponding to the general consideration of aspects in the context of labelling sustainable software products in Section 3 and of the mapping to sustainable websites in Section 4, the following consideration will also dwell on a definition, criteria, and possible forms of representation.

A. Criteria

The complexity of finding criteria for a green website based on the presented definition with focus on the energy consumption is less than for sustainable websites. Hence, based on previously published results, we propose the following criteria for green websites:

- *Optimization of Content and Data Transfer*: Applying green web engineering principles, like using caching, can have a positive impact on the energy consumption of the website [12]. It is important to continuously monitor the resulting effects of applying these principles to the induced energy consumption.
- *Optimization of Files*: The criteria *Number of Files* as well as the *File Size* are important and influence the resulting energy consumption while using a website. We proofed this by different energy measurements [12]. Both, file number and file size, should be kept to a minimum. This minimum cannot be exactly defined and depends on the specific website. The files should be as much compressed as possible as far as the functionality is not reduced.
- *Optimization of Energy Aspects*: Overall, energy is an interesting aspect seen from the view of ecology. On the one side, it is interesting which kind of energy is used to operate the server hosting the website (renewable energy or not). On the other side, the energy consumption should be continuously monitored and optimized during the life cycle of a website. Here, overlaps with the criteria *Optimization of Content and Data Transfer* exist. Additionally, there should be energy management options. A possible energy option for a website can be the deactivation of energy consuming content like animations without minimizing the presented information. Web advertising also looms large regarding the energy consumption while surfing a website [34].

The proposed criteria belong to the website itself, meaning the product and not the whole engineering process and sum up some of the criteria listed separately in Section 4. Similarly to the discussion of sustainable websites, our first step of labelling green websites is to focus on the product. Afterwards, if implementing green web engineering principles and corresponding tools are established, the criteria could be extended to the whole process. For example that means that there need to be energy measurements of the website but no monitoring of the energy consumption of the whole project.

B. Form of Representation

Since, in case of our definition, the focus of a green website is clearly set on energy consumption the label should also concentrate on this focus. Thus, we advance a neutral label similar to the Energy Star or a declaration of the average induced energy consumption.

Indeed, to be able to realize a label presenting energy values based on measurements usage scenarios are necessary. So far, there are different approaches for energy measurements in the context of software [5, 11, 22]but a standardized method to measure the energy consumption of websites is missing. In general, the information on the label is to be kept up to date. Caused by the already mentioned fast-moving nature of websites that leads to changing structure and content of the site it might be necessary to update the average resulting energy consumption more often than in case of other software products.

Hence, a neutral label just informing about the green characterization of the website might be the first step towards more transparency in the context of the energy consumption of the Internet. In order to create a recognition value we recommend to identify an existing label and concrete the

presented criteria to its standards. However, to do so commonly accepted criteria for green websites are necessary. The criteria presented above might represent a starting point to reach a common acceptance.

VI. DISCUSSION

As presented in our paper the core issue what exactly is meant by the term "sustainable software" is not answered yet but the different authors agree on the relevance of bringing sustainability to the ICT field and emphasize the impacts of software on the environment. Many contributions discuss this topic. We referred to a variety of them in order to find a common basis. The labelling process is complicated by different understandings and foci on sustainable software. Nevertheless, by presenting ideas and approaches on the way of labelling sustainable software products we wanted to demonstrate that the potential in this context is high – on condition that basic issues will be solved. The efforts of creating a label can be understood as challenges to solve the still arising questions.

Hence, from our point of view the following questions gain a high importance: What are suitable criteria a label can be based on? How to represent these criteria in a reasonable way? Both, criteria and form of representation, do finally depend on the expectation of the label. In our paper we presented possibilities to find a solution for these questions. Indeed, the concrete aspiration of a label has still to be defined: Is the software product itself considered? Is the software development process considered? Is the whole life cycle of the software considered? Is the software company considered?

Regarding green websites we proposed to concentrate on the three aspects Optimization of Content and Data Transfer, Optimization of Files or Optimization of Energy Aspects (see Section 3). Here, the limitation is to concentrate on the environmental aspects or more specifically the energy consumption and considering the website itself, not the whole process behind.

Indeed, these limitations are not yet defined for sustainable software. However, apart from defining the general set-up for a label and breaking the criteria to reach an awarding guideline, the criteria itself are proposals so far. To find generally accepted criteria, they need to be discussed and weighed. Exemplarily, we will discuss the aspects "rebound and efficiency" and "carbon footprint vs. privacy" in the following paragraphs.

Additionally to the discussion of the criteria itself, further points of discussions will be mentioned in the outlook (Section 7). They are supplements to the addressed aspects (definition, criteria, form of representation, target groups, and stakeholders).

A. Rebound and Efficiency

Many of the criteria presented above are more or less about efficiency. Single aspects of the criteria are either minimized or maximized depending on the nature of the criteria. This is not only true for the *Efficiency* section, but also for the *Feasibility* and *Perdurability* sections, considering the properties *Energy Consumption* (see *Feasibility*) or *Maintainability* (see *Perdurability*) for example. Increasing the efficiency regarding those properties does not necessarily mean that a website in total causes less negative impacts, e.g. carbon dioxide emissions due to server operation, as it would have caused without any efficiency improvements.

To reduce complexity, assume that the number of servers hosting a website is fixed. If there are efficiency improvements to the website, e.g. less data transfer and thus necessary server performance, it is possible to serve more visitors with the now available performance. As a result, in total, there are no savings at all. The emissions remain the same as without any efficiency gains.

The same can be observed with efficiency gains regarding maintainability. Assume a maintenance department with a fixed number of employees who are responsible of maintaining a set of websites. If the maintainability of these websites is improved, the maintenance people can handle more websites in the same amount of time, but in total, the emissions caused by the required office space and infrastructure remain the same. Even if they do not handle more websites, there will be no savings as long as we do not fire any employees and release the then disposable office space (which will indeed have a negative social impact on the affected employees).

Naturally one may argue that without efficiency gains one would have required more servers to serve the same amount of visitors or that one would have required more maintainers to maintain the same amount of websites, but just with efficiency gains without a total reduction, it seems to be impossible to contribute to the EU countries' goal announced at the UN 2014 Climate Change Summit of cutting carbon dioxide emissions to 40 per cent below 1990 levels by 2030 [1].

One may ask, why our criteria are then sticking on efficiency properties to label a sustainable website or rather software. As others found and discussed before us, efficiency gains are necessary but not sufficient to achieve sustainability goals [17, 19]. The effects discussed above are also known as rebound effects. A strong rebound effect may not only compensate, but also even overcompensate the initial energy savings achieved by gains in efficiency. Hence, to face rebound effects, it is not sufficient to simply consider efficiency properties. It is rather additionally necessary to keep an eye on the total savings.

B. Carbon Footprint vs. Privacy

Conducting a Carbon Footprint study is nothing new. Even for websites, it is possible to buy a service that calculates an ongoing Carbon Footprint calculation, called co2stats[11]. Despite the fact that this service is online since 2008 [36], nearly no information except the FAQ on their own website[10] is publicly available, that describes how it exactly works. According to the FAQ, they collect data about the website usage, network traffic, as well as client computers, client location (to get an approximate of the energy mix) and used

[11] http://www.co2stats.com/faq.php

browsers of the visitors of a certified website. The Carbon Footprint is calculated continuously on the basis of the collected data. They claim to buy enough renewable energy certificates with your service-subscription to green the whole website, including approximated energy for the network traffic, as well as for the clients accessing your site. We do not want to discuss whether the co2stats method is suitable to green a website or not. Obviously, you need to collect huge amounts of data about your visitors (type of computer, browser, location, used network connections, accessed pages, usage time, etc.) to get an accurate carbon footprint estimation. All these data has to be stored and processed, which may introduce privacy risks, if the collected data is not anonymized instantaneously. However, according to EU privacy regulations (directive 2009/136/EC [15]), it is generally necessary to obtain visitor's consent before installing a cookie or some other technology necessary for tracking the actions of a visitor on a website. Whether or not such privacy risks may be acceptable for a sustainable website has to be further discussed.

VII. Conclusion and Outlook

In our paper we summed up the aspects that are relevant while creating a label for sustainable software products: definition, criteria, form of representation, target groups, and stakeholders. In order to find a common basis we compared existing approaches and extended them by own ideas. At first, we considered software products in general and focused on websites afterwards. Here, we proposed especially criteria and suitable representations for a sustainability label or rather an eco-label. The presented approaches need to be evaluated in corresponding case studies and duly appropriated. The discussion section highlights open questions and challenges. Overall, based on the previous sections and the literature cited we came to the following findings:

1. In order to move forward in creating a sustainable software label it is necessary to define a general set-up including: aspiration, object of investigation, considered sustainability aspect, focus of by- or in-aspects.
2. It is possible to combine existing approaches of definitions and criteria for sustainable software products and its engineering. A selection of these depends on the result of defining the set-up for a sustainability label for software.
3. A differentiated label presenting details about the awarding basis and quality meets the expectations of the end users in the best way and should be a long-term result. A bold and simple label might be a first step and a starting point for advancements.

Based on these findings the next steps in labelling sustainable software products should include the following activities:

1. The demand and problems of a sustainability label for software products and its engineering need be discussed in general.
2. The criteria for sustainable software products and projects need to be evaluated from a practical proof and broke down to checklists for developers and award guidelines for certification offices.
3. The proposed criteria should be further proofed in perspective of quality criteria for software products and websites. So far they are primarily just laid on findings of sustainability informatics results.
4. Possibilities for certification bodies (Who is awarding the software products?) need to be collected, compared, and evaluated.

Overall, the listings of aspects regarding labelling sustainable software products need to be further developed.

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