Sustainability in Software Engineering - A Systematic Mapping

Kristina Rakneberg Berntsen, Morten Rismo Olsen, Narayan Limbu, An Thien Tran and Ricardo Colomo-Palacios
{Kristina.r.berntsen, morten.r.olsen, narayan.limbu, an.t.thien, ricardo.colomo-palacios}@hiof.no

Abstract: Information Technology (IT) has become a key element in our everyday life, and one of humanity's current challenges is to conserve the environment and attain a sustainable IT development. Therefore, it has become increasingly important how environmentally friendly a software product is during its life cycle and the effects on the environment related to the development, exercise, maintenance and disposal of the software product. The purpose of this study is to outline recent development of frameworks and guidelines in sustainable software engineering. A systematic mapping was conducted which focuses on practices and models that are being used or proposed in this regard. The results reveal different types of models and different criteria for evaluating sustainability properties. In addition, the study indicates an increase of interest in this field in recent years whereas results suggest a handful of prominent authors and venues publishing research within the scope of sustainable software engineering.

Keywords: Sustainable software engineering, systematic mapping.

1 Introduction

IT is used frequently in today's business world and is an essential part of most business strategies. However, the impact of IT has a significant negative impact on the environment. Ehrlich and Holdren [1] presented a function to determine the environmental impact of human consumption. It is estimated that the electricity consumption of the ICT sector will increase by nearly 60 percent from 2007 to 2020. This expresses a need for a more sustainable development (SD) in order to reduce energy consumption and greenhouse emissions (GHG).

In recent years, frameworks and guidelines for sustainable software engineering (SSE) have emerged. A study in 2014 by Ahmad et al. [2] explored the evolution of frameworks and guidelines in the SSE which concluded that "Sustainable development should integrate social, environmental, and economic sustainability and use these three to start to make development sustainable" [3]. There is a definitive trend of research

regarding sustainable software engineering which has led to terms such as Green IT. The focus on Green IT in recent years have shown that SSE is gaining more attention in the IT industry in terms of software products, but also concerning IT management.

Since the GREENSOFT model [4] was presented back in 2011, there has been an increased amount of models and guidelines for sustainable software development (SSD). In addition, there are several suitable definitions for sustainable software, however the authors chose the two following definitions of sustainable software:

Definition 1: "Sustainable software is software whose direct and indirect negative impacts on economy, society, human beings, and the environment resulting from development, and usage of the software is minimal and/or has positive effect on sustainable development" [5].

Definition 2: "The art of developing sustainable software with a sustainable software engineering process so that negative and positive impacts result in and/or are expected to result from the software product over its whole life cycle are continuously assessed, documented, and used for further optimization of the software product" [6].

Penzenstadler et al. [7] conducted a systematic mapping study which focuses on different research topics within SD. It argues that "Software Engineering for Sustainability (SE4S) has received widespread attention in the SE community over the past few years." The study concluded that SE4S was an immature area of research at the time. Their paper however shows clear indications that research within the fields of software engineering models and methods have gained momentum since 2010. Ahmad et al. [2] conducted a systematic literature review research on sustainability studies on software engineering, from which an overview of research activities, limitations, approaches and methods was developed. They came to the conclusion that sustainable development is an emerging challenge for software engineering and needs improvement based on the development process, management, and evaluation. The paper also reported that there were 13 articles discussing approaches and methods of sustainability in software engineering.

According to Ahmad et al. outlines existing systematic literature review publications on sustainable SE [2], [8]. Their emphasis however, was not primarily placed on models and guidelines in the scope of SSE. Thus, in this paper, a systematic mapping to outline proposed practices and explore the field of SD in SE was conducted. In addition, the scope covers the role of sustainable development in the IT industry. The next section will describe the methodology used for this purpose. Section 3 presents the results of the study, and section 4 presents the conclusion.

2 Research methodology

The focus of this study is to outline the "state of the art" of SSE and elaborate on existing and proposed models, guidelines and practices in this regard. Thus, the propulsive research question for this study is:

What guidelines and models exist in current research for SSE?

Considering the nature of the topic, a systematic mapping study was conducted in reference to the guidelines according to Petersen et al. [9]. In the sections that follow,

the research questions (RQs) are described and the correlating metrics for this study is presented.

2.1 Research questions

In order to ensure that this aim is achieved, the authors have developed the following RQs:

- *RQ1:* What are the most cited/reported guidelines/models for SSE?
- *RQ2:* What is the evolution of interest in SSE?
- *RQ3:* What are the most important authors and venues on this topic?

2.2 Search strategy

In this section the search strategy for finding literature on the topic is presented. In order attain relevant data, the most popular academic databases in the field of information systems and computer science were used:
ACM Digital Library (http://dl.acm.org)

- IEEE Xplore Digital Library (http://ieeexplore.ieee.org)
- ScienceDirect (http://www.sciencedirect.com)
- Springer Link (http://link.springer.com)
- Wiley Online Library (http://onlinelibrary.wiley.com/)

Regarding the search string and keywords, the authors experimented with different combinations of search strings in different databases and jointly established them in the final search for papers:

("sustainability" OR "green*" OR "environment*") AND "software engineering" AND ("model" OR "framework" OR "specification")

2.3 Study selection

The main criterion when selecting papers was the focus on papers regarding SSD. Furthermore, the keyword "Green IT" with a focus on the key phrase "green", was a central metric for the study selection. The study was based on recent development in the field. Another metric was that the selected papers should be available through the Østfold University College library. In order to avoid researcher subjectivity, the authors unanimously chose the following exclusion criteria:

- *Based on accessibility*: Libraries that Østfold University College does not have access to.
- *Based on publication date*: Papers before 2010.
- *Based on language*: Papers that are not written in or translated into English.
- *Based on titles*: The title does not indicate any relation to SSD.
- *Based on abstract*: The abstract does not describe SSD.
- *Based on full text*: The content is not relevant to the RQs.

2.4 Study classification

In the study classification the papers that were selected from the initial inclusion phase were grouped according to their keywords. Additional criteria were: name of author, year of publication, and venue. The categories were adapted to fit RQ1 as presented in the results section. After removing duplicates and merging similar keywords, 32 keywords were used as a basis for the following 6 categories:

- *Energy Efficiency*: Papers that present energy consumption calculation methods, energy efficient systems, and/or metrics for optimizing system performance with lower costs.
- *Development Methodology*: Papers that present improved algorithms or frameworks for software development.
- *Process Enhancement*: Papers that focus on specific sub-section of processes used in the life cycle of a software product.
- *Organizational Metrics*: Papers that are directed towards administrations and present evaluation of current procedures or papers that aim to improve these.
- *Life-Cycle Thinking*: Papers that cover all processes in the software product life-span. Papers that evaluate several processes or aim to improve these.

2.5 Data extraction

This section presents the results from the study classification section. The main focus is placed upon IEEE which contains 19 papers. Out of a total of 105, only two authors appear twice, those being Naumann [4] and Dick et al. [10]. The distribution of publication dates shows that there is a majority of papers in the range of 2013 to 2015 with a peak in 2014, which is represented 10 times. Finally, there was arguably a majority of "solution proposal" papers in the selection.

3 Analysis and discussion of results

In this section the findings from the systematic mapping are presented (see Table 1). All selected papers have made it through a filtering process where the level of relevance to the RQs was determined. The data extraction requirements are described in section 3.3.

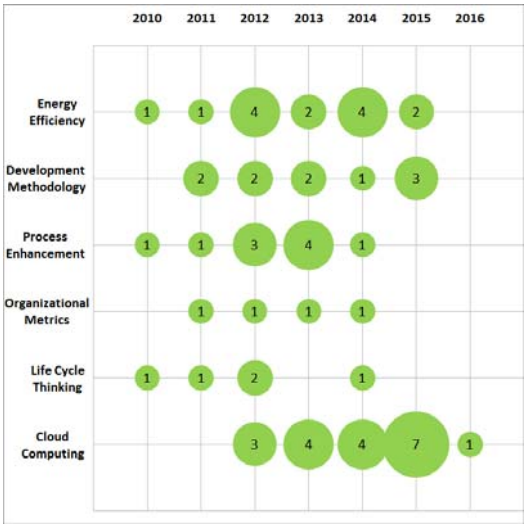

Fig. 1. Distribution of primary studies by categories.

After filtering the papers based on title, keywords, date and abstract, 99 papers were singled out for full-text reading. This resulted in 36 papers. Then they were categorized to answer the RQs, presented in section 3.1.

Table 1. Paper filtering phases.

Library	Total number of hits	Abstract selected	Full text selected
ACM	2754	19	7
IEEE	168	35	17
ScienceDirect	7413	16	7
Springer	7712	7	1
Wiley	3802	21	4
Results	**20824**	**98**	**36**

The next section provides an overview of all the RQs with a discussion to determine if the articles comply with the objective of this study.

3.1 RQ1: What are the most cited/reported guidelines/models for SSE?

The authors extracted 20 articles related to models or guidelines used for SSE. In addition, the authors included papers regarding metrics for these guidelines to answer RQ1. The papers were grouped into 5 categories based on the most frequently occurring topics in the papers (see Table 2).

The literature points to the GREENSOFT model as an early suggested model for "green" and SSD. Early versions of this model have been traced back to 2010 33333[5]. A year later, the model was presented more elaborately. The GREENSOFT model is a

conceptual reference model with criteria and metrics [4]. The other part of the model shows the life cycle for software products better known as "cradle-to-grave" coverage of software whole life cycle of software products.

- *Energy Efficiency*: Energy consumption model [11], Energy benchmarks and metrics assignment [12], Data Center Power Metrics [13].
- *Development Methodology***:** Ripple effects considerations [4], Generic Sustainable Software Star Model (GS3M) [14].
- *Process Enhancement*: Tailored to Agile Methodology [10], Interaction Design Employment [15].
- *Organizational Metrics*: Holistic Green IT strategy [16], Green Performance indicators [17].
- *Life-Cycle Thinking*: "Cradle-to-Grave" - optimization [4], Life-cycle assessment [13].

Table 2. Distribution of topics in papers regarding RQ1.

Mapping	Energy Efficiency	Development Methodology	Process Enhancement	Organizational Metrics	Life Cycle Thinking
[17]	X				
[15]		X	X		
[10]			X		
[18]	X				
[19]		X	X		
[20]		X		X	
[14]		X		X	
[21]				X	
[12]	X		X		X
[22]	X				
[4]		X	X		X
[5]	X		X		X
[23]			X		X
[16]			X		X
[24]		X	X		
[25]		X	X	X	
[13]	X				X
[26]		X	X		X
SUM	**6**	**8**	**11**	**4**	**7**

According to the results, there is a growing attention on the aim for sustainability in every stage of software development. The impact of software on the environment is not solely due to the hardware or servers it makes use of. Davor Svetinovic [25] argues that requirement engineering is fundamental to the process of making complex sustainable systems. Additionally, Mahmoud et al. [17] proposed that testing phase, which was neglected in the GREENSOFT model, should be included in the software product life cycle since it can be environmentally detrimental as well. Thus it can be observed that researchers now regard the life cycle of software from a more comprehensive perspective.

3.2 RQ2: What is the evolution of interest in SSE?

Our findings from this systematic mapping shows that although sustainability is not supported by traditional software engineering methods [27], there exists a significant increase of interest for developing both reliable and long-lasting software with SSE methods [28]. As illustrated in Figure 4, there has been an increase in interest for SSE during the past four years. The graph represents the results from our systematic mapping where 36 primary studies were selected and the years on which they were published. Areas of interest varies from energy savings (green IT) and business processes to non-functional requirements that are aligned with sustainability principles [29]. In the last four years there has been an increased number of publications in sustainability for software engineering in various domains [2]. The most interesting publications are articles regarding SSE frameworks or models. Dick et al. [10] presents a model that integrates Green IT aspects into software engineering processes with agile methods in order to produce "greener" software from scratch. Burger et al. [30] formulated a methodological approach which aims to formulate adequacy conditions for concepts of sustainability. As well as illustrate a categorical framework with the required general concepts, and propose a conception of sustainability based on the capability approach.

There has been a significant increase in interest in SSE between 2011 and 2014. The graph shows a drastic decrease from 2015. Since the graph represents the results from our systematic mapping, the decrease of interest may be caused by our lack of findings of published papers in the year of 2015. Thus the graph may be lacking in representing the real-life situation when it comes to interest in SEE.

3.3 RQ3: What are the most important authors and venues on this topic?

Findings indicate two venues that distinguish from the others:

- The International Workshop on Green and Sustainable Software (GREENS) is an annual workshop focusing on green software engineering. The first workshop was in 2012. The goal has been to bring together academics and practitioners to exchange experiences and results of previous and ongoing practices and research on green and sustainable software.
- The Harnessing Green IT book is the other venue that produced several hits even in the preliminary studies. Two of which made it through the data extraction and by so, deemed as relevant literature regarding green IT and green computing. The book presents the principles, methods and solutions used in green IT practices.

Table 3. Distribution of topics in papers regarding RQ3.

Venues	Reference
International Conference on Software Engineering (ICSE)	1
Journal of Sustainable Computing: Informatics and Systems (SUSCOM)	2
International Conference of Chilean Computer Science Society (SCCC)	1
Harnessing Green IT: Principles and Practices Book	2
International Workshop on Green and Sustainable Software (GREENS)	3

Journal of Systems Engineering	1
Conference on Human Factors in Computing Systems (CHI)	1
ACM SIGSOFT Software Engineering Notes	1
Latin American Computing Conference (CLEI)	1
International Conference on Evaluation and Assessment in Software Engineering (EASE)	1
Journal of Environmental Impact Assessment Review	1
Conference on Advances in Computing and Communications (ICACC)	1
The 4th International Conference on Ambient Systems, Networks and Technologies (ANT)	1
IFIP Advances in Information and Communication 2010	1
Green Technologies Conference (GreenTech), 2015 Seventh Annual IEEE	1
Total	**19**

Regarding authors, Stefan Naumann, Markus Dick and Eva Kern contributed to the most papers [5], [4], [22], [10] whereas the last one was published in the GREENS workshop 2013. Birgit Penzenstadler is accredited the most unique papers in the data selection [31], [27], [7], [8]. Table 4 outlines an outtake of the distribution of authors contributing to papers in the extracted data. The table illustrates the collaboration of Eva Kern, Markus Dick and Stefan Naumann in several papers in this selection. The data extraction resulted in a variety in terms of authors with the given scope. There is circumstantial evidence of the aforementioned authors conducting research that is accepted in SSD venues (see Table 4). Furthermore, the contribution of Birgit Penzenstadler is mentioned due to a systematic mapping studies on software engineering for sustainability seeing as this contribution is relevant reference literature for further research.

Table 4. Author contributions in extracted literature.

Author	Contribution
Dick	[9], [10], [16], [28]
Kern	[9], [16], [28], [29]
Ardito	[18], [38]
Naumann	[9], [10], [28], [29]
Penzenstadler	[5], [12], [33]
Murugesan	[22], [32]

4 Conclusion

In this systematic mapping, current practices in sustainable software engineering are outlined. This paper focuses on models that are being used or proposed in this regard. Sustainable development is the emerging challenge for software engineering and needs improvement based on the development process, management and evaluation. Similar research has been done in the SSE field [2], [7]. This paper differs regarding the focus on models used in the SSE field. The results reveal different types of models and a different set of criteria for evaluating sustainability properties. The sustainability aspect is being taken into account in every step of software development.

In addition, there is a clear indication of increased interest in this field in recent years. Results also suggest a handful of prominent authors and venues publishing research within the scope of sustainable software engineering. The importance of SEE is prominent. However, our results may have been lacking due to the strict inclusion/exclusion criteria. As for future work, other databases may provide different results, thus it can be a motive for further exploration.

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