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Puzzling out Software Sustainability

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ABSTRACT

Software Sustainability is gaining importance and, as occurs with any other new discipline, there are still many misconceptions and misunderstandings surrounding it. In this paper we attempt to clarify the different aspects of software sustainability, from organizational sustainability to software sustainability, exploring the latter in great depth by considering its three dimensions. We also present an overview of the research that has been developed around software sustainability, which was obtained after reviewing the best known workshops and conferences on green and sustainable software and some journals. The results obtained principally address the environmental dimension, and specifically green software design, quality and requirements.

1. Introduction

Sustainability is demanded by present-day society; we have become aware of the need to cut down on our energy consumption and reduce our carbon footprint. When pursuing strategic sustainability, the impact of technology is important from two different points of view. On the one hand it helps organizations tackle environmental issues (virtual meetings, the dematerialization of activities, improvements to logistics, intelligent transport systems, more efficient processes, etc.), while on the other, technology itself is often responsible for major environmental degradation (the amounts of energy consumed by the engineering processes used to manufacture products). It is thus possible to differentiate between IT as an Enabler (or Green "by" IT, i.e., using IT to reduce the emissions in all the areas of an organization) and IT as a Producer (or Green "in" IT), which considers the impact of IT on the environment.

Software technology is no exception and could contribute to the attainment of smart cities, smart buildings, and a variety of software applications with which to improve sustainability. However, as Stroustrup [1] has observed, "our civilization runs on software", and the ever-increasing demand for software provokes the production of non-sustainable software.

Fortunately, IT sustainability is becoming a must for organizations, many of whom are aware of the need to develop sustainable solutions, and sustainability is now recognized as a competitive business advantage. This reality can also be perceived in software. In fact, as Penzenstadler et al. [11,12] remark, sustainability has recently started to receive recognition as a quality objective for software systems, as software security has been addressed from the 1980s onward, or software safety since the early 1990s.

Software Sustainability is gaining importance and, as occurs in any other new disciplines, although some efforts have been made, there are still many misconceptions and misunderstandings. We specifically wish to make Software Sustainability a Software Engineering (SE) concern, as the software industry and software engineers must be aware of and can be affected by all aspects of software sustainability. Our objective is, therefore, to attempt to clarify the different aspects of software sustainability, in addition to providing a general overview of the main proposals used to assess them.

Sustainability is a widely-used term, several definitions of which can be found in literature [2]. That most frequently adopted is found in the United Nations (UN)'s Brundtland report, which defines sustainable development as the ability to "meet the needs of the present without compromising the ability of future generations to satisfy their own needs" [14]. According to the UN, sustainable development needs to satisfy the requirements of three dimensions, which are society, the economy, and the environment.

Although there is a general assumption that relates sustainability to the capacity of something to last a long time, this is a restrictive interpretation, since two fundamental pillars that underpin sustainability can be identified: "The capacity of something to last a long time" and "the resources used"

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Another important issue is the scope of "sustainability". If we attempt to apply the concept of sustainability to the software arena, we find that sustainability may have an influence on several "levels". On a general level, the organization should be sustainable and, as stated in ISO 26000 [6], organizations around the world (this thus being applicable to software industries and their stakeholders), are becoming increasingly aware of the need for and benefits of socially responsible behavior, and the objective of social responsibility is to contribute to sustainable development.

An organization will be sustainable depending, among other issues, on the sustainability of its business processes, services and information systems (IS). IS sustainability depends, in turn, on the sustainability of ICT (Information and Communications Technology) sustainability, which is composed of communications and IT (Information Technology) systems, whose sustainability is determined by the sustainability of their hardware and software components (see Fig. 1).

A complete compilation of these definitions can be found in Calero and Piattini [2]. However, the main problem is that proposals mix up the different levels and do not always clearly specify which level they are dealing with. This paper will focus specifically on the software sustainability level (in gray in Fig. 1), and an attempt will be made to ensure that the concepts, definitions, components and levels related to it remain clear.

2. Software sustainability

Some authors consider that the dimensions of the UN's Brundtland report (society, economy and environment) are not sufficient when applied to Software Sustainability. For example, Penzenstadler and Femmer [10] propose five dimensions of sustainability for software systems: Individual, Social, Economic, Environmental and Technical sustainability. At the second GREENS workshop at ICSE 2013 [7], two different working groups, which were created during the workshop, proposed different sets of sustainability dimensions. One of them identified: social, environmental, economic, and technical sustainability (the first three dimensions are derived from consolidated definitions of sustainability, while the last is specific to IT and refers to traditional system qualities). The other working group produced a model containing four views of sustainability: business, technical, environmental and social. Recently, in Lago et al. [8], four dimensions were included in a framework for software-quality sustainability requirements: social, environmental, technical, and economic.

In Fig. 2, we identify three kinds of resources needed by software life cycle processes: human resources (people involved in carrying out the software processes), economic resources (needed to finance the software processes) and energy resources (all the resources that the software consumes during its life). These three types of resources can be used to directly obtain the dimensions of software sustainability:

- Human sustainability: how software development and maintenance affect the sociological and psychological aspects of the software development community and its individuals. This encompasses topics such as: Labor rights, psychological health, social support, social equity and livability.
- Economic sustainability: how the software lifecycle processes protect stakeholders' investments, ensure benefits, reduce risks, and maintain assets.
- Environmental sustainability: how software product development, maintenance and use affect energy consumption and the usage of other resources. Environmental sustainability is directly related to a software product characteristic that we call "software greenability".

We do not consider technical sustainability because it does not map directly onto any of theresources needed for software construction. Technical issues, such as maintainability or evolvability, will influence the other three dimensions.

3. Green software

The definitions of Green Software found in literature are rather chaotic as regards concepts, and it is possible to find terms such as green software, green through software, green in software, etc.

It is necessary to differentiate between Green BY (when the IT is the tool used to support sustainability goals) and Green IN (when the term "green"' is related to the IT, software or hardware themselves). In general, the definitions of green software mix these two perspectives. Fig. 3 integrates all the definitions, from Software Sustainability to Green in Software. In this paper we are concerned with Green IN Software, in which the objective is the software itself.

Green in Software Engineering is part of Green in Software and therefore of Green Software. The main goal of Green in Software Engineering is to include green practices in both the software development and the other activities that are part of Software Engineering. ISO/IEC/IEEE defines software engineering as "the application of a systematic, disciplined, quantifiable approach to the development, operation, and maintenance of software; that is, the application of engineering to software" [5]. This definition can be used as a basis on which to define Green in Software Engineering as those practices which permit the application of engineering to software by taking into consideration environmental aspects. The development, the operation, and the maintenance of software are therefore carried out in a green manner and produce a green software product (or service) (Fig. 4).

4. Software sustainability research snapshot

In this section we shall use the diagram shown in Fig. 3 to present an overview of the research that has been developed around software sustainability.

On the highest level, it is possible to evaluate software sustainability by assessing each of the three dimensions. Going down the levels, and as a part of the Green IN software, it would be possible to assess aspects directly related to software engineering or to other aspects of software (such as software development governance, etc).

Finally, as part of green in software engineering it is possible to assess how green the process, the product, the operation, etc., is. In order to obtain a more specific classification of the works regarding green in software engineering, we decided to use the SWEBOK [4] as a framework to classify them, since we believe that this is the best and most widely used framework in the software engineering community. SWEBOK includes 15 areas related to software engineering, but not all of them have been used in our classification. We excluded foundations areas (e.g. Computing Foundations, Mathematical Foundations and Engineering Foundations) because they are too general and basic to be useful for classification purposes

It is worth emphasizing that it is not our intention to develop a systematic mapping study. Our main objective is to discover where the research efforts concerning software sustainability are being carried out in the software community. We have, therefore, decided to work using only specific software forums, and have ignored other forums in which it might be possible to find works related to different aspects of software sustainability.

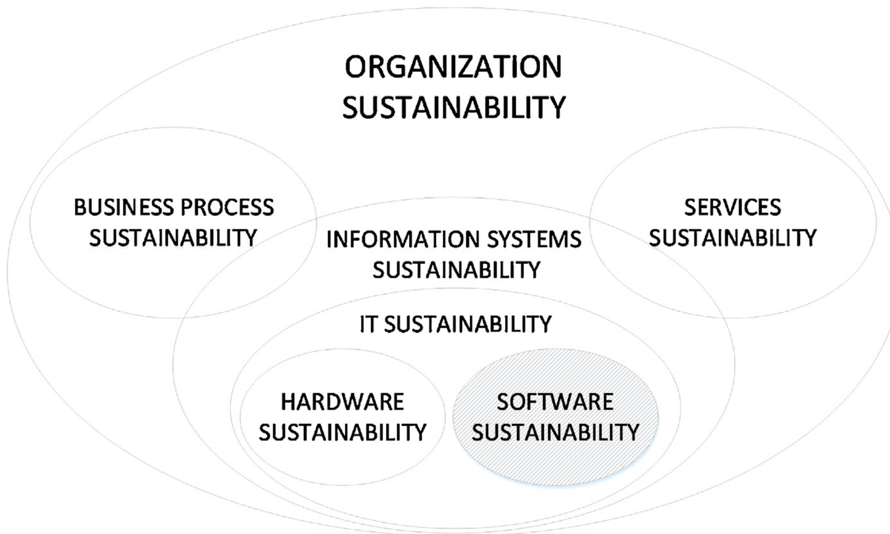

Fig. 1. Sustainability levels.

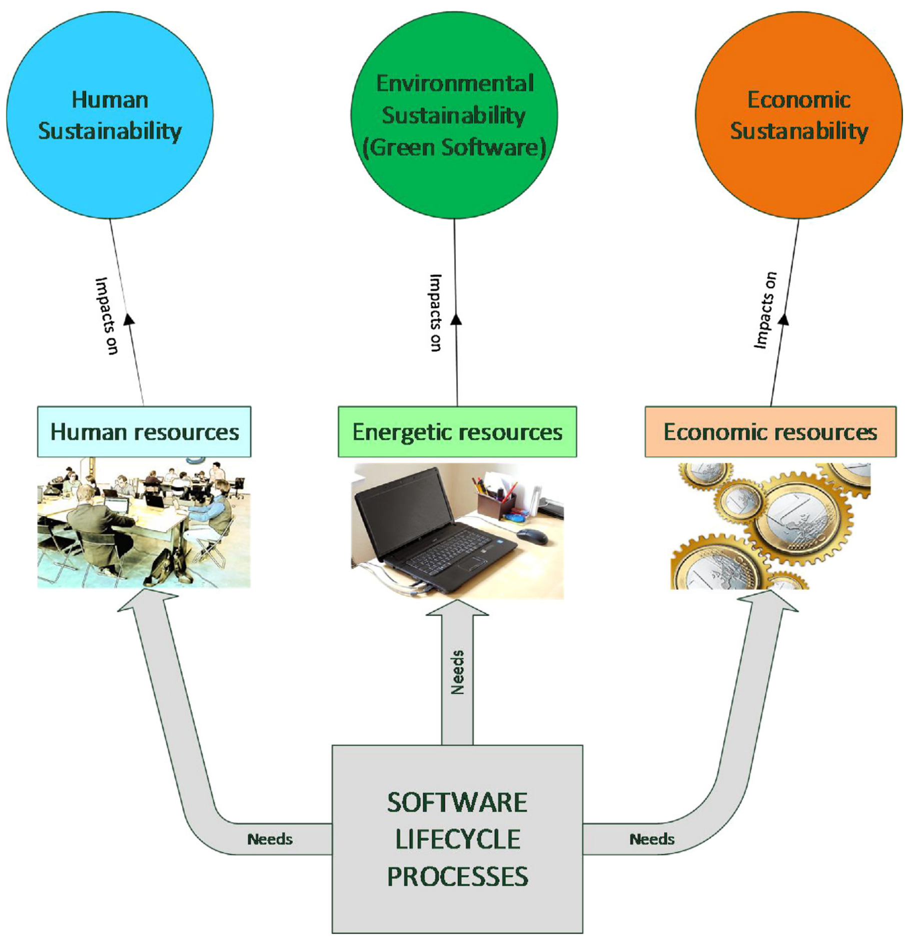

Fig. 2. Software Sustainability dimensions.

4.1. Search information

The results shown herein have been extracted from the main workshops and conferences related to green and sustainable software: Green and Sustainable Software (GREENS), Software Engineering Aspects of Green Computing (SEAGC), Green in and by Software Engineering (GIBSE), Requirements Engineering for Sustainable Systems (RE4SUSY), Energy Aware Software-Engineering and Development (EASED), Sustainable Software for Science: Practice and Experiences (WSSSPE), Measurement and Metrics for Green and Sustainable Software (MEGSUS), the Green In Software Engineering workshop (GINSENG) and ICT for Sustainability (ICT4S). We have analyzed the contributions made to these forums between 2012 (when the first workshops began) and 2015 (the last

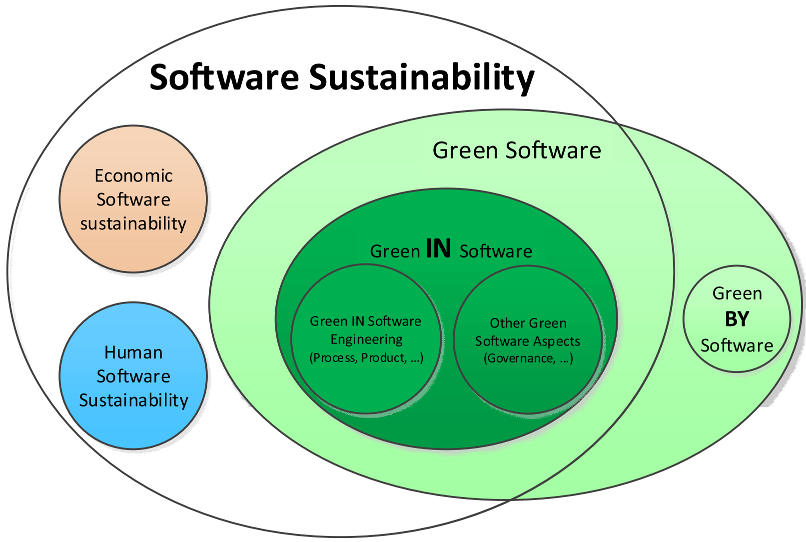

Fig. 3. From Software Sustainability to Green in Software.

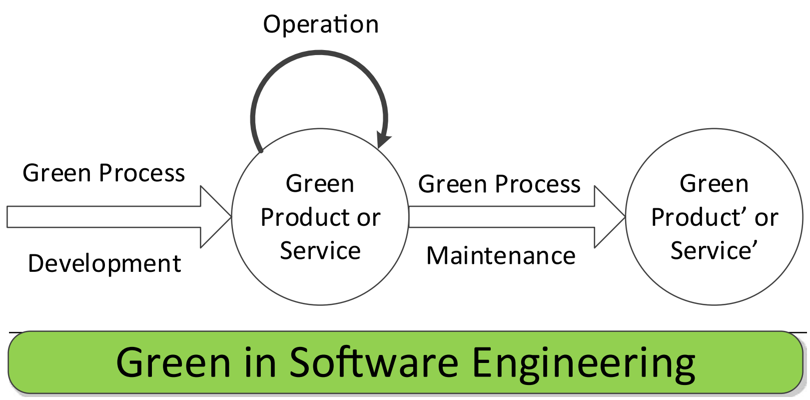

Fig. 4. Green in Software Engineering.

editions held). It should be noted that not all of them had editions in all the years reviewed (shown in grey in the tables below).

We have also reviewed some of the main journals related to the area: IEEE Software, Journal of Systems and Software (JSS), IT Professional, Information and Software Technology Journal (IST), Communications of the ACM (CACM), IEEE Transactions on Software Engineering (TSE) and ACM Transactions Software Engineering and Methodology (TOSEM). The search took place at the beginning of July 2016, and the results presented for 2016 correspond with January to July (even though for some of the journals issues for the next months were available). The only exceptions to this are: (1) IEEE Software, for which the last issue reviewed corresponds to July-August and (2) IT Professional, for which the last issue available corresponds to June).We included a paper in our classification if it was about green in software, whereas those papers about green by software were excluded.

The process was conducted by both authors. As a first step, the first author discovered a list of all the contributions to the workshops and conferences and a selection of the journal papers related to software sustainability, classifying each one according to the sustainability dimension, the SWEBOK area or a general topic in the case of its being out of the scope studied. This was done by reviewing the abstracts of the papers, although the complete paper was read when necessary. The second author then supervised the classification, and this resulted in a coincidence of 90% between both authors and a list of agreements/disagreements. Any disagreements were solved by looking at and discussing the contents of the paper under dispute.

The final result of this protocol was the classification of all the papers. The main conclusions reached will be explained in the following section.

4.2. Searchresults

As can be seen in Table 1, 45% of the total number of papers obtained from the forums studied were selected. We do not provide the complete list of papers because we have reviewed all the papers published in the forums and journals mentioned. It should be noted that any workshop keynotes have been eliminated and that, in the case of the ICT4S, we have only reviewed the papers related to those categories used for classifications purposes in this paper.

The sources from which the most significant works were selected were GREENS and RE4SUSY (19 and 18 papers, respectively), followed by IEEE Software (11), EASED and WSSSPE (7), SEAGC (6) and MEGSUS and ICT4S (5). The other sources provided an insignificant number of works. In fact, two of them (GIBSE and TOSEM) did not provide us with any papers since the papers in them were, in the case of GIBSE, about green by software (our exclusion criteria) or, in that of TOSEM, they contained no papers on the topic.

In both of the cases commented on (Table 1a and b) it would appear to be evident that conferences and workshops have, to date, been the forums chosen for publication, rather than journals. This

Table 1
Total of publications reviewed and selected.

a) Total of papers reviewed

	2012	2013	2014	2015	2016	Total
GREENS	12	10	8	6		36
RE4SUSY	6	6	8	7		27
EASED		8	4			12
GIBSE		4				4
WSSSPE		7	5	16		28
SEAGC		7	4			11
ICT4S		4	1	12		17
MEGSUS			5	3		8
GINSENG				4		4
IEEE SOFTWA	0	5	7	2	4	18
JSS	1	1	3	3	4	12
IT Professiona	3	6	0	1	1	11
IST	1	0	1	0	0	2
CACM	0	1	0	1	0	2
TSE	0	0	1	0	0	1
TOSEM	0	0	0	0	0	0
	23	59	46	55	9	193

b) Papers selected

	2012	2013	2014	2015	2016	Total
GREENS	5	7	4	3		19
RE4SUSY	5	3	6	4		18
EASED		4	3			7
GIBSE		0				0
WSSSPE		4	3	0		7
SEAGC		2	4			6
ICT4S		3	1	1		5
MEGSUS			2	3		5
GINSENG				2		2
IEEE SOFTWARE	0	4	4	1	2	11
JSS	0	0	1	0	1	2
IT Professional	1	0	0	0	1	2
IST	1	0	1	0	0	2
CACM	0	0	0	1	0	1
TSE	0	0	1	0	0	1
TOSEM	0	0	0	0	0	0
	12	27	30	15	4	88

c) Percentage of papers selected per forum

GREENS	53%
RE4SUSY	67%
EASED	58%
WSSSPE	25%
SEAGC	55%
ICT4S	29%
MEGSUS	63%
GINSENG	50%
IEEE SOFTWARE	61%

is logical when keeping in mind how new this discipline is and that there is little work of sufficient maturity. More papers are, however, beginning to appear in journals.

Upon studying the percentage of papers selected with regard to the papers reviewed (Table 1c), it will be noted that we have selected more than half of the contributions of most of the workshops and conferences (RE4SUSY, MEGSUS, EASED, SEAGC, GREENS and GINSENG). With regard to journals, owing to the low number of contributions of most of them, we have calculated this percentage solely for IEEE SOFTWARE, with 61% of contributions selected.

The results obtained once the selected papers had been classified are shown in Table 2a–c. The first conclusion is that in all the years studied, and in the case of both journals and conferences or workshops, the percentage of works on "Green in Software" is much greater than that published in the other two dimensions ("Economic" and "Human"), comprising around 92% of the contributions of the study.

Table 2
Papers classification.

a) Papers in Workshops and Conferences

	2012	2013	2014	2015	Total	
ECONOMIC		2	0	0	0	2
HUMAN		0	0	2	0	2
GREEN IN SOFTWARE	Req	3	3	3	2	11
	Design/Construction	2	8	9	2	21
	Testing	0	1	0	0	1
	Maintenance	1	2	1	2	6
	Config. Mangmt/Sw Mangmt	0	0	0	0	0
	Process	0	0	1	0	1
	Models and Methods	0	0	1	0	1
	Quality	2	9	6	7	24
Total		10	23	23	13	69
Total Green in Software		8	23	21	13	65

b) Papers in Journals

	2012	2013	2014	2015	2016	Total	
ECONOMIC		0	0	0	0	0	0
HUMAN		0	0	1	0	2	3
GREEN IN SOFTWARE	Req	0	0	1	1	1	3
	Design/Construction	1	3	2	0	0	6
	Testing	0	0	0	0	0	0
	Maintenance	0	0	1	0	0	1
	Config. Mangmt/Sw Mangmt	0	0	0	0	0	0
	Process	0	0	1	1	0	2
	Models and Methods	0	0	0	0	0	0
	Quality	1	1	1	1	0	4
Total		2	4	7	3	3	19
Total Green in Software		2	4	6	3	1	16

c) Global total

ECONOMIC			2
HUMAN			5
GREEN IN SOFTWARE	Req	14	81
	Design/Construction	27	
	Testing	1	
	Maintenance	7	
	Config. Mangmt/Sw Mangmt	0	
	Process	3	
	Models and Methods	1	
	Quality	28	

In the Green in software dimension, the most popular areas of research are generally Quality and Design/Construction, followed by requirements (there are small variations between conferences and workshops and journals). There are, meanwhile, few research efforts as regards testing, models and methods, process and maintenance, and management is the only area to which contributions have not been made.

It is not possible to find a clear pattern of evolution in any of the areas (with the possible exceptions of quality and design/construction, which seem to contribute with a significant number of papers each year).

We should point out that Penzenstadler et al. [12,11] have a similar goal to ours and also use the SWEBOK for their classification. The main differences between the two works are: (1) [12] is an SMS on SE for sustainability, while our work is simply an overview of software sustainability in some software forums; (2) Penzenstadler et al. [11,12] include the IN and the BY perspectives while ours is focused only on the IN perspective. Taking into account these differences, and focusing exclusively on the results, we can identify similarities in the results obtained for the requirements, design, quality and the economic perspectives, and some dissimilarities as regards the maintenance, management and process perspectives.

As practically half the papers from the selected forums did not fit into Software Sustainability, we have also analyzed these papers. The results are shown in Fig. 5, in which the topic studied by each paper has been used to classify them. 54.7% deal with Green Hardware (most of them with Green in Hardware), followed by Green by software, Green IT-ICT and data centers. It should be noted that we have included a "general" dimension in which we have included those papers related to Software Sustainability but from a broad point of view, and it is not therefore possible to classify them in the framework presented.

5. Conclusions and future work

Although still in its early stages, software sustainability is a very important research topic that will be of great importance in the next few years. Like any immature discipline, there is some confusion and misunderstanding with regard to the concepts and terms used. Penzenstadler et al. [11,12] state that there is a lack of consistent terminology in this area and we have, therefore, attempted to address this weakness in the first part of our work (Sections 1 to 3). We have also attempted to clarify the different levels and perspectives that can be taken into account when discussing software sustainability.

Most of the research into IT sustainability has concentrated on Sustainability "BY" IT, i.e., the support that IT could provide as regards improving the sustainability of systems and organizations. It is only very recently that researchers have begun to focus on Sus-

	Percentage
General	18,9
Information Systems	7,5
Green BY software	32,1
Green Hardware	54,7
Green IT-ICT	18,9
Data Centers	15,1
Cloud Computing	7,5

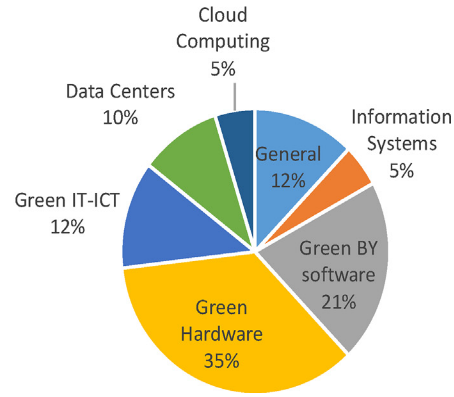

Fig. 5. Areas dealt with in the remaining papers.

tainability "IN" IT, mainly with regard to the communications and hardware components of Information Systems.

We have created a snapshot of the main areas that enable software engineering to become more sustainable on which research has focused to date. This has been done by using three important dimensions of software sustainability: human, economic and environmental (green in software), while several areas of SWEBOK have been used to classify the works into the green in software dimension.

We have studied the main conferences and workshops related to software sustainability and some of the main journals in the area, obtaining 193 papers. Almost half of the papers reviewed (88) are specifically related to software sustainability and most of them were published in workshops and conferences (65). This may appear to be logical if the youth of the discipline is considered, although the number of papers published in journals has begun to increase over the years and it is necessary to wait until the discipline becomes mature to discover whether this is, effectively, the reason.

With regard to the papers on Software Sustainability, the dimension with the greatest number of contributions is the "Green in Software" dimension, whereas the "Human" and the "Economic" dimensions have hardly been addressed in software journals and conferences.

Upon studying the "Green in software" dimension in greater depth, it was noted that the most popular areas of research are generally quality and design/construction, followed by requirements. The areas in which the fewest research efforts have been made are management, testing, models and methods and process. These results are mainly the same as those obtained in Penzenstadler et al. [11,12], which would appear to confirm the research tendencies in the area.

We have also analyzed the topics in the papers that did not fit into Software Sustainability, obtaining that almost half deal with Green Hardware (most of them with Green in Hardware), followed by Green by software, Green IT-ICT and data centers.

As a future work, directly related to the survey presented in this paper, we plan to study and analyze the different research problems related to the achievement of software sustainability and the existing methods employed to solve them, in order to complete the actual state of the art of the discipline.

As a conclusion, we defend the need to carry out more research into both the human and economic dimensions of software sustainability, thus reinforcing that which is stated in [3] as regards the need for real transdisciplinary research among the fields of Software Engineering, Psychology, Sociology and Economics. Most of the existing sustainability research is derived from the fact that most of the proposals regarding sustainability have come from the manufacturing" world, and we must be aware of the huge difference between "manufacturing/industrial" processes and software processes (the latter are people-intensive, with a tremendous variance in inputs and outputs in each execution; they are more risky, in addition to being more difficult to verify, etc. [9]. We have to create the intellectual and technical tools needed to take these differences into account; merely transferring the existing research on manufacturing sustainability to software sustainability is not valid.

As software researchers, we must, and can, contribute toward improving software sustainability, thus providing organizations with models, methods and tools that will reduce the environmental, human and economic impact. It is also fundamental to validate proposals and to cooperate with industrial partners in order to verify the feasibility of the proposals. As [13] remark: "Irrespective of perspective, reflections on the intersection of sustainability and technologies demand theoretically well-founded analyses and close empirical studies in order to create valuable knowledge on how they interact".

As software practitioners, we must start considering environmental issues in software construction from the very first stages of software development, and throughout all of the software process lifecycles. However, practitioners should be aware that efficient and validated techniques and tools are not as yet available for this purpose.

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