Software Sustainability from a Process-Centric Perspective

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Abstract. ICT significantly contributes to the global carbon dioxide production. In the last years the research addressed the problem of increasing ICT sustainability from different perspectives. In this paper this problem is addressed from a software process perspective. Sustainability of software process is approached in a systematic way by defining a core set of processes that represent the activities to be performed in order to introduce and integrate the greenness culture in an organization developing software. The processes have been defined so that they can be measured in terms of process capability according to the ISO/IEC 15504 standard. The relationships between process capability and sustainability are discussed as well.

1 Introduction

Problems related to the *environment* preservation and to the sustainable development are among the most important human beings have to face today. Because software intensive systems and applications are more and more pervasive in all the activities of everyone's day life, environmental impact of any related aspect has indeed become an issue. The global ICT industry is claimed to account for approximately two percent of global carbon dioxide (CO_2), a figure equivalent to the aviation industry [5]. The aspects related to the sustainable design, development, use, maintenance and disposal of software and software-intensive systems (that in this light can be denoted as Green Systems) have been in the last years addressed from the following different perspectives:

- *Development of Green Systems:* systems to be designed adopting technical solutions able to minimize the power consumption during their usage, and using materials having a reduced environment impact during production and disposal. In fact, for some ICT products (such as servers or set-top boxes) it is essential to reduce the power consumption during use, because the use phase comprises the largest share in their total life cycle impact; for others it is more important to optimize their design for recyclability or to avoid negative effects during end-of-life treatment. [6, 7, 8, 10]. These issues are addressed by the ISO 14000 family of standards related to environmental management. It aims at supporting organizations to minimize how their operations negatively affect

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the environment (i.e. cause adverse changes to air, water, or land); to comply with applicable laws, regulations, and other environmentally oriented requirements, and to continually improve in the above aspects [16, 17].

- *Design of Green Software Products:* software products shall be designed in order to adopt efficient algorithms able to reduce both the direct carbon footprint of software (e.g. power consumption due to the CPU cycles) and the indirect effects on sustainability (i.e. the effects depending on the system where the software is executed and on the domain where the system is used). Although software doesn't consume energy, it deeply affects the consumption of hardware equipment, for this reason software is indirectly responsible for energy consumption. [9, 11]
- *Green Software Development:* the focus in this case is on the whole software life cycle, including the development phase, that shall follow principles and adopt techniques aiming at optimizing sustainability. This is strictly related with the concept of green software engineering. [1, 12, 13]

What is still to be addressed in a complete manner in the literature is the sustainability of the software process. Software process determines and drives the organizational *modus operandi* in all the activities directly and indirectly related to the software development. The availability of models and methods for assessing and improving software process in terms of sustainability contributes to the sustainability of software products as well as to spread the organizational greenness culture.

In this paper we provide definitions and principles related to the green and sustainable software process. In addition we refer to the well-known standards ISO/IEC 12207 and ISO/IEC 15504 to clearly identify the core activities related to green and sustainable software process as well as a way to evaluate the capability of an organization in such activities.

This paper is structured as follows: in Section 2 principles and definitions about sustainable software process are provided, in Section 3 factors determining the sustainability of software process are addressed as well as possible sustainability objectives. In section 4 a core set of process definitions (according to the requirements of the ISO/IEC 15504 standard) able to cover the software process sustainability is provided. In Section 5 the relationships between process capability (measurable by means of the ISO/IEC 15504 standard) and sustainability are discussed. Finally, in Section 6 possible future advancements are identified and conclusions are provided.

2 Green and Sustainable Software Process Principles and Definitions

In this section key definitions, taken from the literature, are provided in order to give a clear picture of what green and sustainable software process means and its relationships with key other concepts.

Green & Sustainable Software:
software, whose direct and indirect negative impacts on economy, society, human beings, and environment that results from development, deployment, and usage of the software are minimal and/or which has a positive effect on sustainable development. [1]

Green & Sustainable Software Engineering:
the art of developing green and sustainable software with a green and sustainable software engineering process [1].

Therefore it is the art of defining and developing software products in a way, so that the negative and positive impacts on sustainable development (i.e. a pattern of growth in which resource use aims to meet human needs while preserving the environment so that these needs can be met not only in the present, but also for generations to come) that result and/or are expected to result from the software product over its whole lifecycle are continuously assessed, documented, and used for a further optimization of the software product.

Software lifecycle is a concept introduced in the '80s [19]. The software lifecycle is a framework in which the activities related to development, exercise, maintenance and disposal of software product are identified, and their order of performance established. In other words, a lifecycle describes or prescribes how an organization shall perform the software development, maintenance and disposal.

In [1] the green software lifecycle is addressed with the main objective to assess the ecological, social, human and economic compatibility of a product during its whole life cycle.

A related concept, but different from the software lifecycle, is that of software process. Software process is a collection of general definitions of the interrelated activities that can be suitably performed during the development, maintenance and disposal of a software product. The whole software process is usually considered as composed of different processes each of them covering a specific activity. This approach is established in the ISO/IEC 12207 [3] standard that gives the requirements for an extended set of processes suitable for software development. For this reason hereafter we refer to software processes instead of a unique software process.

The relationships between software lifecycle and software processes can be represented as Figure 1 shows. Software processes are general activities having their own characteristics and requirements. Software processes are mapped on a specific software lifecycle that establishes which processes are used, their sequence of performance and their possible iterations. In general software processes are independent of the specific software lifecycle they are applied in.

Each software process represents a set of interrelated activities (including also the use of resources), that transform inputs into outputs to be used for developing a specific product. Their actual usage in real projects determines the software lifecycle.

Software sustainability can be approached from a process-centric perspective and a definition of Green and Sustainable software process can be given as follows.

Green and Sustainable Software Process:
Software process that meets its (realistic) sustainability objectives, expressed in terms of direct and indirect impacts on economy, society, human beings, and environment that result from its definition and deployment.

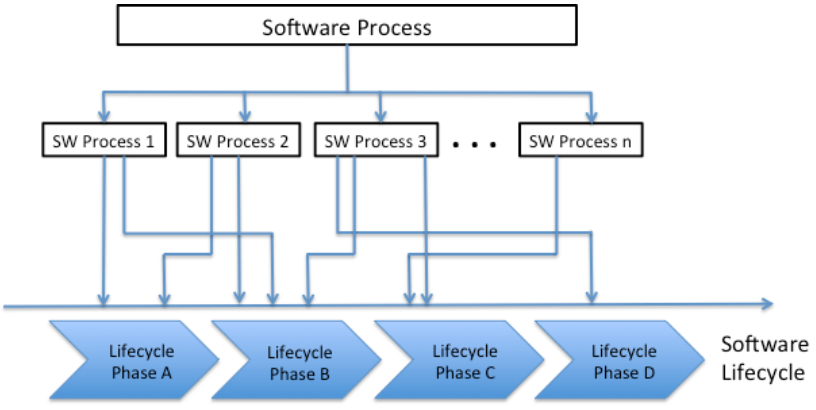

Fig. 1. Software Lifecycle vs. Software Process

3 The Sustainability Factors of the Software Processes

The process sustainability factor (i.e. the part of the carbon footprint due to or save by the specific process used in developing and managing all the aspects and phases related to the software lifecycle) cannot be ignored.

In fact, the way the interrelated activities composing the whole software process are performed and managed may significantly impact on the whole sustainability of the software.

The principal sustainability factors directly impacted by the process are identified in the following list:

- *Power Consumption*: this factor is directly related to the efficiency of the software process. Inefficient processes require unnecessary workload with a consequent waste of power and then avoidable CO_2 emissions.
- *Paper Consumption*: the amount of paper consumed in a software development project depends on the media used for sharing information and knowledge within the organization. Knowledge management and communication infrastructure as well as their usage depend on the procedures defined in the processes. Infinite examples can be provided showing waste of paper in distributing and using documents.
- *Fuel Consumption*: travels and face-to-face meetings can be reduced (with a consequent reduction of fuel consumed) both introducing suitable technologies and defining suitable processes to guide their usage.

The three factors indicated above are not mutually independent. For instance, it would be expected that savings in terms of paper consumption are mitigated by an increase in terms of power consumption. Generally speaking, progress in the efficiency of producing software means that the same results can be obtained using less input. By increasing efficiency, input factors (e.g. energy input) can in principle be saved in absolute terms. However, in practice these savings may be balanced out or even

overcompensated by an increase in demand for the output, because the output is getting cheaper in terms of money or time or by a different destination of saved income that can be spent on other goods or services. These phenomena are known as rebound effects [14, 15].

The rebound effect shall be taken into account when sustainability objectives are defined for a software development project. The overall sustainability objective for software processes is to support sustainable development, minimize resource requirements and produce minimal waste. More detailed sustainability objectives can be derived as:

Carbon Footprint: the amount of carbon dioxide a software development, management, or maintenance activity shall emit. The discussion of techniques and methods for calculating reference values to be associated to the carbon footprint objective is out of the scope of this paper.

Energy: the amount of energy consumed during the software development. This objective is easier to be established because it is based on real power consumption no matter how energy is produced.

Waste: the amount of physical, energy or process resources consumed in activities that add no visible value to software and users.

Travel: travelling time required during the software development. This objective can be refined according to the type of vehicle used.

4 Addressing Sustainability in Software Processes

In this section, a model in which the concepts of sustainability and software process are integrated is provided. Once such a model has been given, the evaluation of the degree of process sustainability of an organization will be possible.

For this purpose we refer to the ISO/IEC 12207 standard.

To address sustainability issues in software process we define a set of sustainability-specific processes representing the activities to be performed in order to introduce and integrate the greenness culture in the software process. The definition of this new set of processes follows the rules of the ISO/IEC 12207 and ISO/IEC 15504 standards.

According to those rules a process definition shall contain the following parts:

- Process Title: a definition that conveys the scope of the process as whole
- Process purpose: the statement of the goal of performing the process
- Process outcomes: observable expected results of the successful performance of the process

In the following the core set composed of three processes necessary to embrace the process sustainability as a whole is provided. According to the definition of green and sustainable software process provided in Section 2, these processes represent a way to introduce and establish an organizational *modus operandi* able to support the development of green software.

These three processes are introduced and described using a tabular format respecting the process definition rules provided above.

4.1 Sustainability Management Process

Sustainability management process aims at ensuring the achievement of established sustainability objectives in software development.

It can be decomposed into four phases that are described in the following:

Preliminary phase: the sustainability principles and criteria that will drive the sustainability-related decisions are established. In the following we indicate as *sustainability activities* those activities performed in a product development (technical, managerial and support activities) aimed at satisfying the sustainability objectives.

Planning phase: the sustainability activities to be deployed in the development of the product are identified. The planning of the sustainability activities is produced and the necessary resources to accomplish with it are identified and allocated.

Monitoring phase: the performance of the sustainability activities is monitored for its compliance with the planning. Possible deviations are treated until solution.

Supplier sustainability control: the sustainability requirements for supplied products are defined and a monitoring policy is agreed.

A tabular representation of the process definition is provided in Table 1.

Table 1. Sustainability Management Process

Process ID	SUS.1
Process Name	Sustainability Management
Process Purpose	The purpose of the Sustainability Management Process is to ensure that products, services and life cycle processes meet sustainability objectives.
Process Outcomes	As a result of the successful implementation of the Sustainability Management process: 1) Principles and criteria for sustainability are established. 2) The scope of the sustainability-related activities for the project is defined. 3) Activities for sustainability are planned and implemented. 4) Tasks and resources necessary to complete the activities for sustainability are sized and estimated. 5) An organization structure for sustainability (responsibilities, roles, reporting channels, interfaces with other projects or OUs …) is established. 6) Activities for sustainability are monitored, sustainability non conformities are reported, analysed, and resolved. 7) Agreement on sustainability policy and requirements for supplied products or services is achieved. 8) Supplier's activities for sustainability are monitored.

4.2 Sustainability Engineering Process

Technical solutions for sustainability shall be injected into the development process in order to comply with defined sustainability objectives. The sustainability engineering process addresses the application of techniques and methods able to guarantee that the sustainability activities are suitably integrated into the engineering activities to achieve defined sustainability objectives.

Techniques and methods are applied on the basis of an analysis aimed at verifying their suitability to achieve sustainability objectives.

Possible change requests are analyzed, their impact evaluated and the planning modified accordingly.

A tabular representation of the process definition is provided in Table 2.

Table 2. Sustainability Engineering Process

Process ID	SUS.2
Process Name	Sustainability Engineering
Process Purpose	The purpose of the Sustainability Engineering process is to ensure that sustainability is adequately addressed throughout all stages of the engineering processes.
Process Outcomes	As a result of the successful implementation of the Sustainability Engineering process: 1) Factors affecting sustainability (e.g. resource consumption sources) are identified 2) Sustainability analysis is performed in order to determine the sustainability impact of factors affecting sustainability 3) Sustainability objectives are defined for the product development 4) Green principles are applied to development processes to identify techniques and methods suitable to achieve the sustainability objectives. 5) Techniques and methods for sustainability are applied 6) Impact on sustainability of change requests is analysed

4.3 Sustainability Qualification Process

Software and system development may need the acquisition and use of external resources (as for example: core engineering tools, engineering support tools, management support tools). The overall sustainability is affected by the sustainability of these external resources, then this process addresses the assessment of sustainability of external resources and their management.

To achieve the purpose of this process, a sustainability qualification strategy and a plan that implement such a strategy are to be prepared and implemented. Moreover the outcomes of the qualification are to be documented.

A tabular representation of the process definition is provided in Table 3.

Table 3. Sustainability Qualification Process

Process ID	SUS.3
Process Name	Sustainability Qualification
Process Purpose	The purpose of the sustainability Qualification process is to assess the suitability for sustainability of external resources when developing a software or system.
Process Outcomes	As a result of the successful implementation of the Sustainability Qualification process: 1) Sustainability qualification strategy for external resources is developed. 2) Sustainability qualification plan is developed and executed. 3) Sustainability qualification documentation is written. 4) Sustainability qualification report is produced.

5 Evaluating and Improving Software Processes Sustainability

According to the well-known motto: *You cannot control what you cannot measure* [4] the availability of means and models for measuring the quality of processes and then for improving them, if necessary, is crucial. The compliance of the process definitions provided in section 4 with the ISO12207 and ISO/IEC 15504 requirements allows the use of the ISO/IEC 15504 for measuring the capability of such processes.

Process capability is a concept related to the probability a process meets its goal in terms of quality of outcomes, costs and time; the higher the capability of a process the lower the risk of missing its objective. This concept is represented graphically in Figure 2.

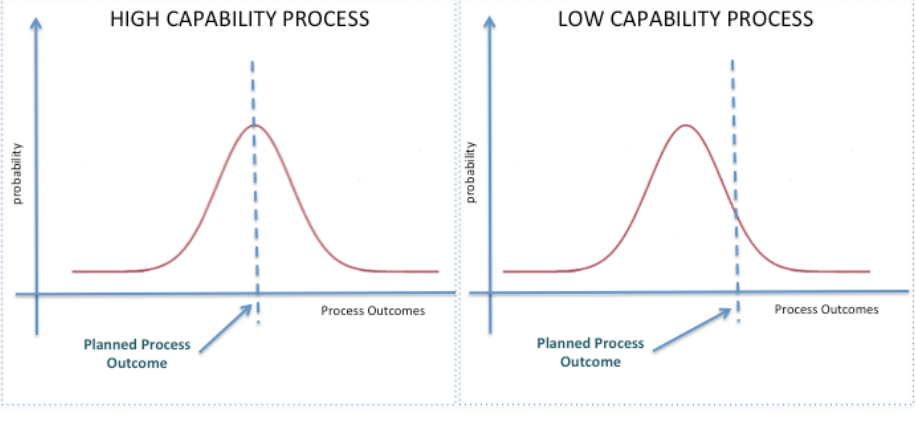

Fig. 2. Software Process Capability graphic representation

The measurement of process capability is addressed in two well-known reference models: the CMMI [18, 20] and the ISO/IEC 15504 [2]. The latter, in particular, provides a flexible way to the determination of software process capability because it is structured in two dimensions: the process dimension and the capability dimension.

Table 4. Capability Level vs. Sustainability in SUS.x processes

Capability Level (CL)	SUS.1	SUS.2	SUS.3
0 Not Performed	There is a general failure to attain the purpose of the process. There are little or no easily identifiable work products or output of the process		
1 Performed	The organization is generally able to ensure that products, services and life cycle processes meet sustainability objectives.	The organization is generally able to ensure that sustainability is adequately addressed throughout all stages of the engineering processes related to software/system development	The organization is generally able to assess the suitability for sustainability of external resources when developing a software or system
2 Managed	The organization follows specified, planned and tracked procedures to deliver work products (conformant to specified standards and requirements) related to: • Definition of sustainability principles and criteria • Planning and monitoring of sustainability activities (including those performed by suppliers) • Resource and infrastructures allocation for sustainability	The organization follows specified, planned and tracked procedures to deliver work products (conformant to specified standards and requirements) related to: • Definition of sustainability objectives • Application of suitable techniques to achieve them.	The organization follows specified, planned and tracked procedures to deliver work products (conformant to specified standards and requirements) related to sustainability qualification strategy definition, planning, deployment and reporting
3 Established	The procedures identified for CL 2 for each SUS.x process are implemented using a documented standard process or an approved tailored version of it		
4 Predictable	A quantitative understanding of the capability of each SUS.x process and an improved ability to predict and manage their performance and the quality of the related work products is achieved by the analysis of detailed performance measurements		
5 Optimizing	The performance of each of the SUS.x process is monitored against organizational business and efficiency goals. Quantitative feedbacks are collected and used for improvement purposes.		

The process dimension comprises processes defined according to certain requirements that are including those of the ISO/IEC 12207; the capability dimension provides a measurement framework composed of process attributes, and process indicators as well as a mechanism to rate the capability of processes.

In the case of processes related to sustainability defined in Section 4, achieving a higher capability level means that the structure of the organization supports the achievement of the sustainability goals in developing software and that the confidence in achieving such goals is enforced.

Nevertheless, the Process Capability and Process Sustainability concepts are different. There is not a direct relationship between process capability and sustainability; in other words, a process having high capability can have a low sustainability and vice-versa.

The three processes defined in Section 4 are, in our understanding, enough to cover all the basic aspects of sustainability in software process . In Table 4 the meaning, in term of sustainability, of the achievement of a certain capability level according to the ISO/IEC 15504 measurement framework is explained.

To be noted that nothing can be directly inferred about the sustainability of the final product from the achievement of a certain capability level according to the ISO/IEC15504 scheme. On the contrary, measuring capability of the processes defined in section 4 means evaluating, from a managerial and technical point of view, the behavior of an organization when it deals with sustainability in developing software.

Applying a capability determination mechanism to the set of processes defined in section 4 can be considered as a contribution in the evaluation of the greenness of an organization and it may support it for improving its greenness as well.

6 Conclusions and Future Works

This paper aims at contributing in the current studies for solving the problem of the ICT sustainability by widening the perspectives from which it is addressed. ICT sustainability has been addressed in this paper by discussing first the factors directly related to the software process. Then a process model composed of the definition of a core set of processes able to address the basic activities to be performed in order to introduce and integrate the greenness culture in organizations developing software has been provided. These processes would represent an addendum to the ISO/IEC 12207 process set and, while they do not impact on the actual Process Reference Model of the ISO/IEC 12207, they influence the way most of those processes are performed because they inject sustainability issues in the whole software development process.

These processes have been defined according to the requirements of the ISOI/EC 15504 standard in order to make possible their assessment in terms of process capability. Finally, the relationships between process capability and sustainability have been discussed.

This paper is to be considered as an initial step towards the definition of a sound framework aimed at integrating the sustainability with the traditional quality

characteristics of the software process as productivity, efficiency, and suitability for purpose. To do that we intend to continue with in this promising discipline by performing ISO/IEC 15504 actual process assessments of the core set of sustainability processes defined in this paper, in order to get feedback and possibly extend or modify them.

We are also investigating the definition of a Process Assessment Model for Sustainability and Capability starting from the existing ISO/IEC 12207 and ISO/IEC 15504 standards. To do that the processes defined in the ISO/IEC 12207 standard should be revised with the aim of injecting sustainability-related outcomes and practices. It would be a way to make the ISO/IEC 12207 greener. Moreover the Process Attributes of the ISO/IEC 15504 standard should be revised along with the related indicators in order to make it suitable to provide a measurement of the sustainability level of the software process as well.

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