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Chapter

Green and Sustainability in Software Development Lifecycle Process

Mohankumar Muthu, K. Banuroopa and S. Arunadevi

Abstract

This chapter gives an insight of GREENSOFT Model for sustainable software engineering. In today's world, computing devices are extensively by all for many purposes. They consume lots of energy even though they reduce energy consumption. Computers are used extensively while developing software. Existing software engineering models do not pay much attention to green computing that focuses on the effective use of natural resources. Sustainability of resources is the key. The GREENSOFT model of software engineering proposes a methodology in which Green IT practices are used, which will reduce the energy consumption of computers while developing software.

Keywords: software engineering, environmental informatics sustainability, ICT, Green IT, GREENSOFT model

1. Introduction

Today, software is extensively used by all of us for commercial and noncommercial purposes and it is controlled by various entities. The total energy consumption by ICT is between 5 and 9% and is going to increase annually by 6–9%. (**Figure 1**) [23]. In India, the exiting ICT facilities have the energy performance index ranging between 230 and 310 kWh/m^2/year. The greenhouse gas emissions by ICT is estimated to be 2.8% in total global emissions, but as usage of ICT can also reduce the emission rate by 15%. This calculation is on consumers who use ICT devices. But energy consumption levels can be further reduced from the current levels if we apply green software development lifecycle. The existing Software Development Life Cycle process framework is not adequate when concerned with energy consumption. This is mainly due to the lack of awareness in the Green Based Software Development life cycle process. The existing Green based software development model namely Green Reference Model is focuses on the three phases of the process called development, usage, and end of life. But the GREENSOFT model does not provide Green-based approach in entire Software Development Life Cycle phases which is a major setback of GREENSOFT model.

The existing model for Green software engineering does not consider the Requirement, Design, Coding, Testing and Implementation phases of SDLC. In order to achieve green software engineering the entire software development process is to become Green.

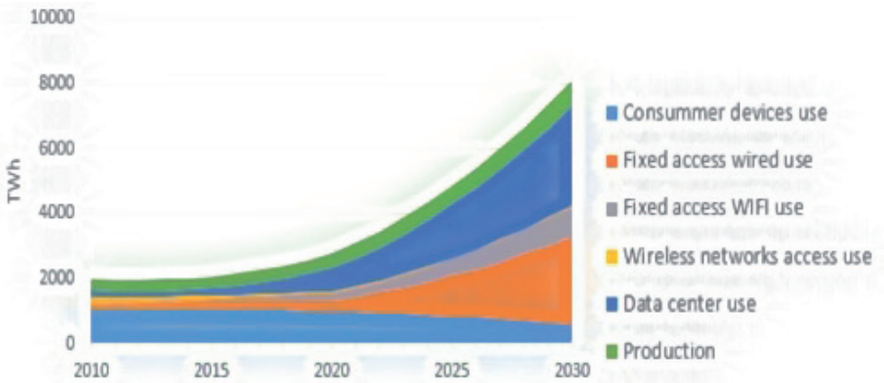

Figure 1.
ICT electricity consumption.

2. Environmental informatics

Sustainability has become a very essential factor to consider doing business in recent times. If that business has fails to maintain sustainable development it receives significant public criticism and they may lose the market [1].

The usage of computing power is to develop the more sustainable world [2]. The answer for the ecological crisis can be solved by knowledge acquisition. The development of feedback information should be concerned with model makers and system analysts. Environmental Informatics (EI) [2] is the combination of information systems of problem-oriented knowledge from the fields of management and environmental science and computer science. EI is emerged for the requirement of domain-specificity. The computer scientists have the challenge of designing the information processing system for using the environmental data.

The Computational Sustainability (CompSust) [2] is closely associated with the Institute for Computational Sustainability (ICS) with funding starting from 2008 by the U.S. National Science Foundation. CompSust is developed by ICS as "inter disciplinary field to balance the needs (environment, economical and societal) of sustainable development using computer and information science, operations research, applied mathematics, and statistics. The Brundtland definition for CompSust community refers to address the need of basic human." "Balancing" might address the issue to some extend with no reference of deeply normative issues which are connected to distributive justice. Thus, an algorithm can resolve normative issues, which is yet to be developed for greening ICT.

Greening ICT in industry application can run in design phase, classification of ICT systems development phase, execution of software systems phase and complex installation phase and in software development of the Life cycle of ICT systems [3] there are a lot of changes to save energy. The energy can be saved efficiently by using computing resources and avoiding recurring work such as recompiling. Based on World Commission on Environment and Development (WCED) [2], "sustainable development" could be defined as sustainable system use of a system to fulfill its function (F) for a time (L).

3. Sustainability

The goal of sustainability is to provide a common elucidation of the word "sustainability" without actually relating it to any specific context [2]. To perform this,

they will first conclude the sustainability definitions which described as a broadly used term for the ability of something for long lasting time. Some other definitions for Sustainability are as follows.

- Define sustainability as follows "the ability to be overseen at a steady level without depleting environmental assets."

- The Brundtland report from the United Nations (UN) defines sustainable development as the ability to "meet the present needs without compromising the future generation abilities for their own needs."

- Environmental sustainability ensures that the environment is the ability to refill itself at a quicker rate than it is damaged by human actions. For instance, the use of recycled material for IT hardware production helps to conserve natural resources.

3.1 Sustainable software engineering (SSE)

Sustainable software engineering [4] motive is to create reliable, lifelong software that meets the needs of user's requirement and also tried to reducing ecological impacts; its aim is to generate better software so there is no need to compromise future generations' opportunities.

3.2 Green and sustainable software engineering

Green and sustainable software engineering [5] is the skill of creating green and sustainable software in relation to the process of green and sustainable software engineering. The skill of describing and making software products in a way, the positive and negative effects on sustainable developments of the Software Development Life Cycle process constantly assessed. The assessed details are maintained as records and may be utilized for a software product process optimization [25].

3.3 Software engineering for sustainability

The objective of software engineering for sustainability [6] (SE4S) is tried to create a tools and technique in order to reach the conception of software sustainability.

Based on [24], purpose of green and sustainable software engineering [24] is the improvement of software engineering. During the entire life cycle of software system which targets the direct and indirect consumption of natural resources and energy and the aim is to track, access, everlasting measure and optimize these realities.

SSE [7] aims to develop consistent, lifelong software that satisfies the needs of customers and also tried to reduce the negative impact on the financial, humanity and the ecological system [9]. The software engineering sustainability process tries to balance the business and technical advancement in the environment. IT (Information technology) has played a very important role to tackle issues of ecology and various types' ecological issues. However, these can be measured separately. The first consideration is to IT which could be used to mitigate ecological issues [26]. Green IT is defined as "the study and practice of design, developing, using, and disposing of computers and peripherals, and servers effectively without affecting the environment" [8]. Greening through IT [10], conversely is the center of attention on how IT may create a wider range of additional - civilization sectors for further sustainable IT application field. In a wide sense, computers are everywhere and consist

of both specialized and generic systems. This report focuses on computers that constitute significant loads in buildings and specifically investigates energy-efficiency opportunities in five broad computer form factors: desktops, notebooks, small-scale servers, thin clients, and workstations. While the number of tablets in homes is increasing, the energy use of these products is relatively low, and the saving opportunity–is minimal due to existing battery charger regulations and market pressure for achieving the high efficiency in enhancing the battery life [11] which can have main impacts on economic and the social at the worldwide, which makes ecological and power issues of software worldwide concerns too. According to the Annual Energy Outlook 2017 published by the US Energy Information Administration (EIA), energy consumption is expected to increase by no more than 5% between 2016 and 2040, with the sector of electric power being the largest primary energy consumer. On the contrary, projections of energy production vary widely due to the production growth dependency on technology, resource, and market. Energy related CO_2 emissions decline in most Annual Energy Outlook scenario [12]. These categories give a sampling of the different types of technology that are being built with the purpose of enabling greening through IT. The IT segment itself is said to be accountable for 2% of global Carbon dioxide emissions [12], and the global impacts of ecology in this aspect includes high amount of energy utilization [14] and utilization of a different variety of other materials [15], making of wastes like e- and hazardous waste. The ES (Expandability Score) score of greater than 690 is considered a high expandability computer and would be subject to the standards for workstations rather than the desktop standards.

The main ecological concerns of trade are the crisis of global energy. According to World Energy Outlook 2010, "the age of cheap oil is over" [16], describing increasing power prices and for the past 30 years, while per capita electricity consumption in the United States has increased by nearly 50%, California's electricity use per capita has been nearly flat, Continued progress in cost-effective building and appliance standards and ongoing. Due to the fast increasing IT demand,, energy utilization of IT is also a needed for investigation [17] The Long-Term Energy Efficiency Strategic Plan calls on the Commission to develop a phased and accelerated "top-down" approach to more stringent codes and standards. It also calls for expanding the scope of appliance standards to plug loads; process. Computers contribute significantly to energy consumption in the commercial sector, particularly in office buildings and schools. In fact, the U.S. Energy Information Administration's analysis of miscellaneous loads suggests that 70% of commercial notebook and desktop energy consumption occurred in these types of buildings in 2011 [4, 18]. These assumptions include the rising IT role in power administration, technological developments.

3.4 Power factor

Power factor correction is important to power supply efficiency. The California (investor-owned utilities) IOUs proposed to include testing and minimum standards for power factor at full load to achieve energy savings on both the consumer side of the meter as well as on the utility side. NRDC (Natural Resources Defense Council) further recommended power factor correction at lower load points, including sleep and off, to increase energy savings [26]. It may be propose a minimum power factor requirement at full load for computers with non-federally regulated power supplies to ensure consistency with other power supply standards, including the federal external power supply standards and the 80 PLUS® program. However, requiring minimum power factor at low loads demands additional technical support to demonstrate technical feasibility and cost-effectiveness that was not available at the time of this effort [29].

3.4.1 Regulations for computers

For the potential energy savings staff have included desktop computers (including integrated desktops and portable all-in-ones), notebooks (including mobile gaming systems, two-in-one notebooks, and mobile workstations), small-scale servers, thin clients (including mobile thin clients), and workstations (including rack-mounted workstations) in the proposed regulations. A thin client is a type of desktop computer that relies on a server or networked virtual machine to provide full functionality, such as data storage and computational power. Staff have excluded other servers, tablets, smartphones, setup boxes, game consoles, handheld video game devices, small computer devices, smart televisions, and industrial computers [26, 29].

3.5 ICT for sustainability

ICT for sustainability (ICT4S) [2] means metamorphic capability of ICT can be used to make our patterns of manufacturing and exhaustion more feasible [26]. At the same time, the history of scientific knowledge has exposed that increased energy performance does not vitally contribute to green development. To create a more sustainable culture in true potential of ICT can be possible with the efforts of politics, industry and consumers.

ICT4S can be part into:

- Sustainment in ICT: accomplishing ICT products, enterprises also economical above their entire existence cycle, basically diminishing the vitality, material streams which summon

- Empowering by ICT: The method for ICT primary angle are secured by Green ICT and making authorize, empower, creation and utilization by TRHCI and EI. In the event that there is something particular to ICT4S as a field, it is the basic viewpoint that difficulties each mechanical arrangement by surveying its effect at the societal level.

3.6 Software sustainability

There are various territories in which programming manageability longings to be connected [21]: framework programming, programming related items, Web based applications, server farms, and so forth. Diverse works are in process, yet the greater part of this worries server farms, which expend extensively best vitality than business office space. As noted in, the core opportunity for energy savings in computers is found in reducing the amount of energy consumed in idle modes; that is, when the computer is on but not being used [27]. Idle modes are the largest opportunity to reduce energy consumption because computers spend roughly half of the time in this "on mode." In addition, high idle-mode consumption greatly increases the effectiveness of power management settings to reduce overall computer energy consumption. Automatic power management settings are often disabled, which means computers are constantly consuming significant amounts of power when not in use (for example, 50 W in idle mode compared to 2 W in sleep mode).

The software sustainability [30] is the one part of the software engineering sustainability should usually be considered into account from the first software stages of development process. This process is not always feasible, because it is not easy to change how developers work. The core opportunity for energy savings regarding computer monitors is to reduce the amount of energy used in active (on) mode. Reducing the amount of energy used in on mode is the largest energy-saving

opportunity because computer monitors spend about 30% of the time in this mode. About 20% of the computer monitors in the market today meet the ENERGY STAR® Version 7.0 standards. The proposed regulations for mainstream computer monitors are slightly more stringent than the ENERGY STAR Version 7.0 specification and about 30% more stringent than ENERGY STAR Version 6.0. About 14% of current models would meet the proposed standards. Most monitors would need to reduce only their power consumption by 3–5 W to comply. This goal can be met by replacing components with efficient light-emitting diode lights, light-emitting diode drivers, and power supplies that are available in the market at prices comparable to the inefficient technologies.

Supportable HCI is a sub-field of **h**uman-**c**omputer **i**nteraction (HCI) that spotlights on the association amongst people and aptitude out of sight of sustainability [2]. Practical HCI had its beginning stage in 2007, when E. Blevis initially exhibited the possibility of Sustainable Interaction Design (SID). Supportability was measured a noteworthy paradigm for the plan of information, as vital in the outline procedure as criteria, for example, ease of use or strength.

Green and sustainable software engineering is the art of progressing green software engineering process therefore it is art of describing and promoting software products in a way [27]. So that the negative and positive impacts on sustainable development that result and or expected to result from the software product over it is whole life cycle are continuously assessed, documented and used for a further optimization of the software products [19].

According to [21], as identified different definitions sustainability, in general it considered from three different dimensions that are provided by the UN that is social, economic and environmental sustainability.

"Green IS and IT" represent to IS and IT products. The author describes what is Green IS and IT. Here, they tried to find out how the software is handled by an organization and how they maintain the emission and practices of disposal of IT spares without affecting the environment, whose objective is to avoid the pollution; Green Information System as inclusive of Green IT comprehensively has to be followed by the developers (people) and in software processes and technologies, and has to be maintained by person or group of person and public goals of program and prospective to influence on the sustainability of software company and communities giving threat for climate transform and other environmental aspects of dreadful conditions (**Figure 2**).

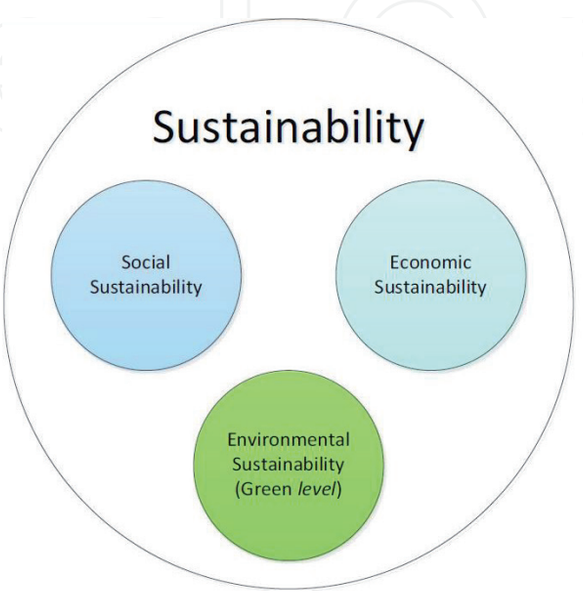

Figure 2.
Sustainability dimensions.

In a broad sense, computers are everywhere and consist of both specialized and generic systems. This report focuses on computers that constitute significant loads in buildings and specifically investigates energy-efficiency opportunities in five broad computer form factors: desktops, notebooks, small-scale servers, thin clients, and workstations. While the number of tablets in homes is increasing, the energy use of these products is relatively low, and the opportunity for savings is minimal due to existing battery charger regulations and market pressure to achieve high efficiency to enhance battery life. Therefore, this staff report does not include analysis on tablet computers. In homes, the most common form factors are notebooks and desktops. While there are more notebooks than desktops in California, the energy consumption of a desktop is more than double that of a notebook. This energy consumption increases when computer monitor energy use is included, which is necessary for functionality. **Table 1** shows estimates of home computer energy consumption with estimates ranging between 2.5 and 4.4% of all home electricity use, not accounting for computer monitor consumption.

Study	Representative Year	Computer Type	Number of Units (Millions, Scaled to CA[20])	Energy Use Per Unit (kWh/yr)	Total Energy Use (GWh/yr)	Percentage of Residential Electricity[21]
EIA MELS Analysis[22]	2011	Desktop	12.8	220	2,816	3.1%
		Notebook	20.6	60	1,236	1.4%
		Total	**33.4**	-	**4,052**	**4.4%**
CEA 2013 Residential Study[23]	2013	Desktop	11	186	2,046	2.2%
		Notebook	11.6	53	615	0.7%
		Total	**22.6**	-	**2661**	**2.9%**
ITI Comment[24]	2013	Desktop	9.6	187.3-296.4	1,800-2,800	2.0 – 3.1%
		Notebook	8.6	58.3-144.7	500-1,200	0.6 – 1.3%
		Total	**18.2**	-	**2,300-4,000**	**2.5 – 4.4%**

3.7 Criteria and metrics for sustainability

Criteria and measurements for supportability of a product items to spoke to in three categories [20] there are

1. Common quality and measurements.

2. Directly related criteria and measurements.

3. Indirectly related criteria measurements.

Based on the first-order effects of ICT supply, Second order effects of ICT use and Third order effects of Systemic effect of ICT respectively. Hardware obsolescence should be a genuine quality property of Green and Sustainable Software,

S. No	Product	Description
1.	Desktop computers	Generally paired with one or more computer monitors, displays, or televisions. Less commonly, the computer is integrated with a screen that is referred to as an "integrated Desktop." Desktop computers are generally responsible for the power management of these devices and can have power management responsibilities for accessories as well, such as printers.
2.	Notebook computers	A computer screen is integrated in the unit, and upgrades and configurability are generally limited. Although they can offer similar functionality to a desktop computer, they are somewhat constrained by space and power dissipation.
3.	Workstations, thin clients, and small-scale servers	A workstation is a task-oriented computer designed for abnormally constant and high workload and durability. On the opposite side of the spectrum, a thin client contains barebones interface hardware that may rely on separate equipment (generally a server or networked virtual machine) to provide full functionality, such as data storage and computational power. A small-scale server is a desktop computer configured to run as a server. While most modern desktops can be used as servers, small-scale servers generally have atypical hardware features and different operating systems than generic desktop computers.

Table 1.
Estimate of home energy consumption of computers.

which belongs to the directly related criterion and metrics model part. Indirectly related criterion and metrics for green and sustainable software address second and third order effects induced by software product [27, 28].

4. Green IT and Green ICT

We expect that computerized joining has aggravated the innovations of calculation and media communications to a degree that makes their division out of date in this unique situation. The term "Green IT" got comfortable after the production of a Gartner report in 2007 [22] and was later on joined by "Green Computing," "Green Software," "Green Software Engineering," and "Green Information Systems (IS)."

The fundamental distinction between Green in IT and Green by IT [21] is the pretended by the IT and the concentration of the greenness. The electricity consumption of computers, computer monitors, and signage displays varies greatly,

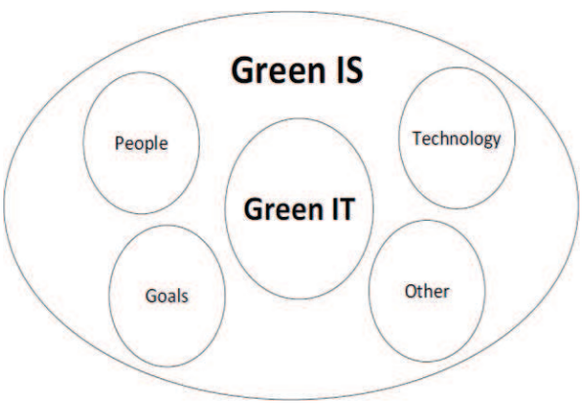

Figure 3.
Green IS and Green IT.

even within models of similar sizes and feature sets. To date, no federal or state regulations provide incentives for implementing cost-effective, readily available technologies to improve the performance of less efficient models. The five form factors considered in this report are desktops, notebooks, small-scale servers, workstations, and thin clients.

With help of the above factors we can find green in and by software and hardware (**Figure 3**). This combination creates the green software and hardware relationship which is Green IT.

4.1 Efficiency standards

The most substantial adjustments to the Energy Commission's draft staff report include dividing desktop computers into four categories with different efficiency levels rather than three categories with a smooth function, adjusting the levels of energy allowances for each category, and modifying the effective dates for the standards. These adjustments could be made while maintaining the magnitude of statewide energy savings. Staff's proposal is an effort to take international experience, stakeholder input, and data analytics and accomplish feasible and attainable energy savings for California in both long and short term. The proposed regulations are divided into three primary categories: desktops and thin clients, notebooks, and small-scale servers and workstations (**Figure 4**).

Category	Products Included
Desktops and thin-clients	Conventional desktops, thin clients, integrated desktops mobile gaming systems
Notebooks	Conventional notebooks, portable all-in-ones (AIOs), mobile thin clients, and two-in-one notebooks
Small-scale servers and workstations	Small-scale servers, high expandability computers (as defined), mobile workstations, rack-mounted workstations, and workstations.

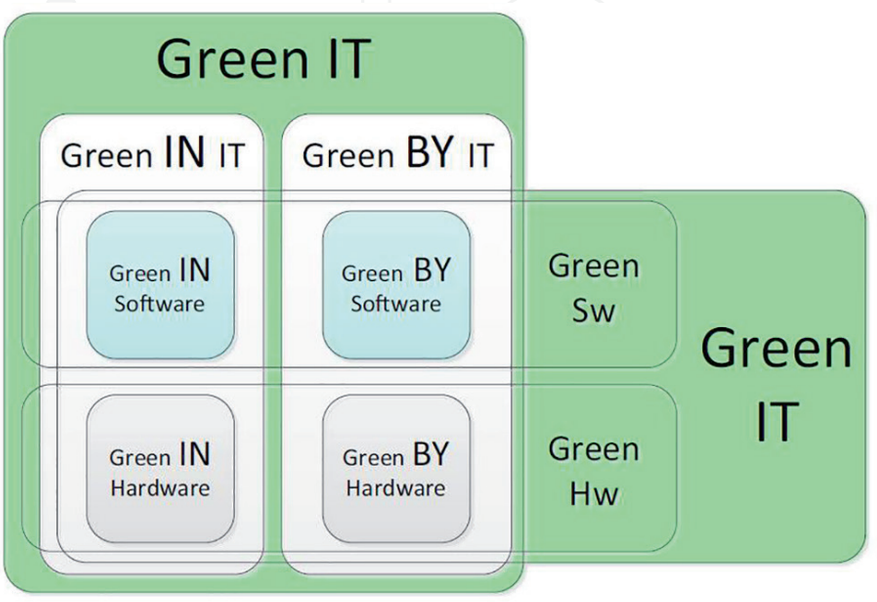

Figure 4.
Green software, green hardware and Green IT.

This procedure concentrates on what ought to be considered in each phase of the improvement routine collection, design, implementation, testing, deployment, and maintenance to create maintainable programming. This comes close to considers some of the classical water fall model methodology. In the requirement phase Marketing executive collect the requirement of the user, based on the software requirement condition the designer going to make a mockup design after getting design approval the developer or software engineer develop a coding, the test engineer going to test the software product whether it is working according to the software requirement specification finally the developing application implemented to the end user side.

5. Research methodology

This research aims at designing; implementing and evaluating new green-based software development life cycle as an alternate to the existing software development life cycle process with the aim of improving the Sustainability in Software Engineering Process.

New green-based SDLC modeling, measurement and evaluation related to Green database design have been identified as the three main approaches commonly used for evaluating the Green Software Engineering system. The primary aim of this research was concentrated on two phases. First, in the requirement phase in SDLC the green and sustainability is maintained with the help of cloud environment settings. Second, in the design phase the green and sustainability is maintained through the database design. The methodology of this study was software paper based data collection sheets, internet search engine and various tools have been studied [31].

5.1 GREENSOFT model

The GREENSOFT representation is a conceptual reference model for [20] "Green and Sustainable Software", Which has the aim to support software developers, administrators, and software users in creating, maintaining and using software in a more sustainable way, the model is shown in **Figure 1**, it comprises a holistic life cycle model for software products procedure models for different stakeholders and recommendations for actions that support stakeholders in developing, purchasing, supplying and using software in a green and sustainable manner.

The reference model contains a life cycle of software products that is in contrast to conventional life cycle software geared to life cycle thinking related to development, usage and end of life and identify the first-order effect, second order effect, and third order effect. The second part of the GREENSOFT model is called sustainability criteria and metrics it covers common metrics and criteria for the measurement of software quality and it allows taxonomy of parameters for evaluating the sustainability of software products.

The model component procedure model makes it possible to classify procedure models that cover acquisition and development of software, maintenance of IT systems and user support that also related to directly related, indirectly related and common quality metrics [35].

The last component of the Model contains recommendations and tools. These support stakeholders with different specialized skill levels in applying green or sustainable techniques in general when developing, purchasing, administrating, or using software products (**Figure 5**).

In the GREENSOFT model, the software product life cycle integrated ICT stimulated product life cycle that can also be credited with "from cradle-to-grave". It is intention to enable stakeholders to evaluate impacts on software development according to the three different levels of impacts [34].

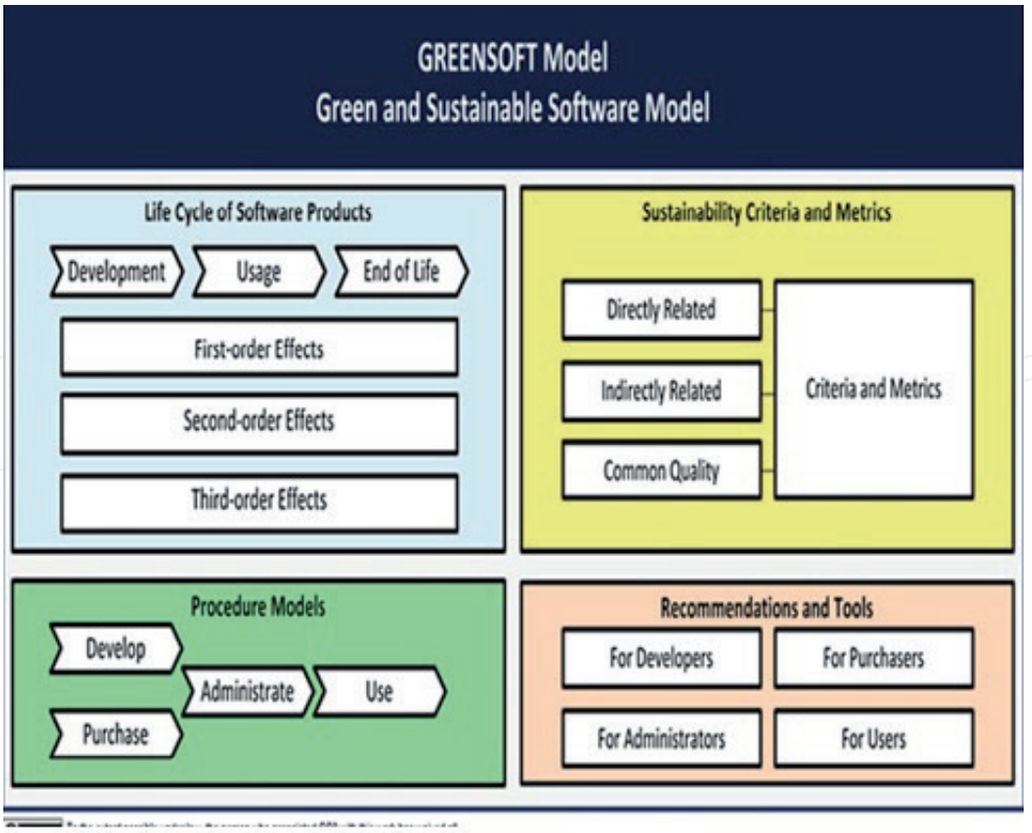

Figure 5.
Green and sustainable software model.

5.1.1 The development phase

The Development stage accounts for impacts [20] on software development that directly results from activities involved in software development as well as indirectly involved activities. Ecological impacts to be measured for example, Electrical Energy that is necessary to power the workstations of software developers and other employees electrical energy and natural resources that are necessary to operate the IT devices (example, Networking Devices, servers, and storages) (second order effects)Social impacts can be working conditions and payment of offshore employees (example developers, typesetters). Third order effects changes in organizations software development approach or life styles.

5.1.2 The distribution phase and the disposal phase

This phase [20] considered the things of software progress that distributing the software product that also includes the environmental impacts (example printed manuals, transportation used for travels, design used for the retail packing (e.g., plastic, biodegradable material or medium of data used for CD/DVD, and user memory Sticks) now a day's software product is offered to download a manuals at time considered the download size of the document [31].

5.1.3 The usage phase

It is impacts that result from deploying [20], maintaining and using of the software product that is nothing but software patches installation and giving training for employees to software usage which regarding in less energy consumption or just switch off the computer when they leave their workplace. To offer services by

computer program requires the consumption of services offered by other servers like data base management systems or Enterprise Resource Planning (ERP). It also causes additional power consumption. To update of a software, the product size influences records transfer process in the IT based infrastructure which are necessary to deliver updates. It also basis further power and resource utilization to the new software to want up-to-date and more prevailing hardware [13]. This new hardware is typically more power efficient than older hardware but on the other hand production of the new hardware and the disposal of the old hardware causes resources and energy consumption [32].

5.1.4 The deactivation phase

If the data cannot be changed easily [20], example because it is stored in a proprietary data design, this may have an impact on economic sustainability of an organization. In this phase even the backing size of data format, if the domain transfers from one application platform to new domain platform. So the deactivation of old database format leads to economic and technical sustainability.

5.1.5 Discussion

The result of this study shows that software application was not environmental friendly in the software development life cycle model. Lack of sustainability is a major flaw in the existing green software model in the following phases such as Requirement, Design, Coding, Testing and Implementation. There are a lot of negative impacts such as high level energy usage, e-hazardous waste, ecological system, financial etc. In this research we proposed a new Green based Software Development Life Cycle in designing; implementing and evaluating phases for a sustainable development to overcome the above factors.

6. Procedure models

At the middle the designing procedure, the whole Life Cycle of the built programming items must be considered [20]. Develop, purchase, administrate, and use. In development of sustainability review study and preview study, process evaluation, sustainability presentation taken into consider about GREENSOFT model. In purchase of software product similar to the ENERGY STAR$^{(R)}$ that indicates whether a software product is energy efficient or meet certain sustainability requirement in the future. In administrate making software available by installing, configuring, and maintaining it. procedure model should implement a continuous improvement cycle that is energy utilization, should be checked regularly in order to improve these with appropriate measures apart from the data center operation includes networking, desktop PC, installed software resources utilization are need to be monitored in the administrative to procedure for users both the professionals and home users need to maintain the guidelines or checklist related to green and sustainable software [33].

6.1 Proposal and methods

Proposal and methods address collaborator with various roles [20] General roles review by the GREENSOFT model are: Planner, Customer, Organizer, and User. On the other hand, there may be more functional roles like Software Architect, Web Administrator, Requirements Engineer, or Application Developer. In assumption,

these can be classified by the general roles mentioned before. Proposal can be best practice examples, utilization reports, guidelines, schedule, etc. Methods can be software, paper-based data collection sheets. There are plenty of tools available on the Internet. More knowledge base or professional Internet search engine would help to find easier.

7. Conclusion

The existing models are used to maintain green and sustainable software in the development and process evaluation. The GREENSOFT model has explained three order effects such as, the first-order effect focus on development to end, second order concentrate on sustainability area and last one focus on recommendations and tools for IT users in creating, maintaining a product for the sustainable development. Our approach is to develop Green IT Star model for green environment which focuses on five phases such as design, implementation, and requirement, coding and testing. The aim of this research is to help IT users in developing a green software and green hardware and improving the Sustainability in Software Engineering Process using Green IT Star model and has attained eco-friendly environment in design and requirement phase. The future research work is to achieve the Green software engineering in each Software Development Life Cycle phases on implementation, coding and testing phase.

Author details

Mohankumar Muthu[1*], K. Banuroopa[1] and S. Arunadevi[2]

1 Department of CS, CA and IT, Karpagam Academy of Higher Education, Coimbatore, India

2 Department of Science and Humanities, Kumaraguru College of Technology, Coimbatore, India

*Address all correspondence to: mohankumar07@gmail.com

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