**Towards Harmonic Existence of Green Computing in Knowledge Society**

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**ABSTRACT**

The upsurge in global warming and release of greenhouse gases is a major issue that intensified over the past years due to the increasing usage of technological resources in our daily routines. That is why a call for going green in the technological field is hardly recommended. This paper reviews various approaches of green computing in five main models - software engineering model, cloud computing, mobile computing, data centers, and educational sector.

**Keywords**

Green computing, Sustainable development, Models, Cloud computing, Mobile development, Education, and Data centers.

# INTRODUCTION

Global warming and climate change are causing the increase of global temperature and the rise of sea levels. The main cause of environmental impacts is people and their harmful behavior. As an example, for such behaviors is the huge amount of CO2 emissions from the industries and vehicles, cutting trees, and the exhaustive use of resources by technology. Studies have showed that the amount of CO2 emissions have been increasing in the past few years [1]. Efforts for reducing harm on the environment must start from changing peoples’ behaviors. Citizens of the planet Earth are responsible for thinking “Green” in all aspects of their lives in order to save and protect their future on their planet. Nowadays, technology has entered people’s lives deeply, until it reached their jobs, homes, and education. As a contribution to achieve environmental sustainability, people can start from changing the way they deal with technology. Most efforts addressed the hardware perspective of green computing with little attention to the importance of the software perspective. Efficient software reduces the use of hardware resources; therefore, reducing energy consumption. In this study, we examine different green computing approaches in the literature in various domains of software development. In particular, we study green approaches in software engineering models, cloud computing, mobile development, data centers. In addition, we highlight the importance of introducing green computing principles in the educational sector.

The remainder of this paper is organized as follows. Section 2: literature review of the topic addressed. . Section 3: Models for sustainable software engineering. Section 4: Green cloud

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computing. Section 5: Green mobile development. Section 6: Green data centers. Section 7: Green computing in education. Section 8 concludes the paper.

# LITERATURE REVIEW

Many efforts were done in the literature with the aim of achieving green computing in different domains and reducing the negative impacts of ICT on the environmental sustainability. Naumann et al. [2] presented a reference model for sustainable software engineering (GREENSOFT) that supports different stakeholders in the whole lifecycle of software production. Berkhout and Hertin [3] defined three levels of ICT impacts on the environment and highlighted the importance of studying their rebound effect in which negative impacts over compensates positive ones. Mahmoud and Ahmad [4] defined green metrics in the stages of software production and stressed on the importance of two stages: requirements definition and testing. The model also discusses the role of software itself in achieving green computing. Capra et al. [5] studied the impacts of software on sustainability and proved that achieving a better performance does not guarantee better energy efficiency.

Atrey et al. [6] studied how the cost of the unlimited services of cloud computing leads to overcompensating the benefits and increases energy consumption and CO2 emissions. Dougherty et al. [7] described a model-driven green technique to avoid over-provisioning of idle virtual resources in cloud servers. The aim of this model is to provide a green auto-scaling technique, for allocating VM configurations, that preserves a satisfactory QoS. The problem is solved as a feature selection problem. Gai et al. [8] presented an energy-aware mobile cloud computing model that takes advantage of cloudlets to reduce energy consumption of wireless communications. Xu et al. [9] described an energy efficient algorithm for VM scheduling inspired by physical principles. Zhao-Hui and Qin-Ming [10] proposed a virtual machine scheduling algorithm that deploys VMs on data nodes with the least growth of energy consumption. Mukhtar et al. [11] presented a green strategy for determining the least energy consuming fog device to offload client application modules. Verma S. et al. [12] presented an energy efficient, but costly, algorithm that integrates load balancing and data replication for Fog-Cloud computing. Previous researches acknowledge that by using virtualization CC (cloud computing) is itself energy efficient technology [13]. A.J. Younge and his colleagues proposed a green cloud framework a few years ago, but it covered only virtualization and data center operations [14].

Mobile devices are becoming an important and irreplaceable resource in our daily life. According to the International Telecommunication Union, the number of registers in the worldwide mobile network operators has already reached more than 4 billion of users [16]. Moreover, based on the International Data Corporation’s statistics, 494 million smartphones were sold worldwide in 2011. The sales of smartphones reached an annual growth of 62% from 2010 till 2011, expecting this increase to continue furthermore [17]. With this huge number of mobiles and mobile users, and taking into consideration their effect on the environment, regarding their energy consumption and the toxic computational operations on the cloud rather than executing them on mobile devices. For example, CloneCloud [18] is a system that allows partial offloading from smartphones to the phone’s clone in the cloud. A similar idea was also investigated by Satyanarayanan et al. [19] and Cuervo et al. [20]. Another example from Chen et al. [21] who introduces a framework allowing heavy tasks on an Android phone to be offloaded to an Android virtual machine in the cloud.

When talking about going green in an environment that encounters rapid ongoing changes in the technological fields, the need for a business to “Go Green” is much needed. Green data centers view a great aspect into offering an energy efficient and ecofriendly computing environment. The burst of data centers began from 1946 where data centers where created by U.S. army to serve the military [22]. A green data center differs from a normal data center through the mechanical, electrical, and computer infrastructure is designed in a way to obtain maximum energy efficiency and minimum environmental damages [23]. Nada and Elgelany [24] mentioned in their article that data center consumes a huge amount of energy as the same time it plays a major role in producing large amount of carbon dioxide due to a fact that data centers are mainly composed of thousands of servers. Uddin et al. [25] mentioned in their study that a data center is composed of thousands of servers and is equal of the amount of a small city.

The topic of green computing in the education sector has been studied intensively in the literature. Many studies were conducted to assess the awareness and knowledge levels of green computing in educational institutions [26, 27]. In [28], German software users were surveyed for a study that addressed the environmental issues of software. The integration of sustainability into computing education was studied in [29], where three different strategies were presented. In [30], different techniques for practicing green computing in universities were proposed.

# MODELS FOR SUSTAINABLE SOFTWARE ENGINEERING

Berkhout and Hertin [3] studied the impacts caused by Information and Communication Technologies (ICTs) on the environment. They presented a summary of the literature on the topic and classified the environmental impacts of ICTs into 3 categories. *First-order impacts,* the most obvious environmental impacts: resource use, pollution, electronic waste. *Second-order impact:* indirect environmental impacts of using ICT. *Third-order impacts:* indirect environmental impacts of using ICT that appear on the long term and may over compensate the energy savings by ICT (rebound effects).

The authors identify that ICTs have both positive and negative impacts, and that each order effects appear based on the previous order effects. A major issue stressed in relation to the third order effects is the ***rebound effect*** of the use of ICT. The first and second order effects show that ICTs have the potential to reduce resources usages and energy consumption. However, a critical question is whether the long-term consumption of ICTs will over compensate the conserved resources.

Naumann et al. [2] presented a reference model for Green and Sustainable software named *GREENSOFT* and gave definitions for *Green and Sustainable Software* and *Green and Sustainable Software Engineering*. The model also performs a refinement for the environmental impacts of ICT, defined in [3], to cover human and social sustainability issues instead of limiting them to environmental issues. The effects were identified as: effects of ICT supply (representing *first-order* effects), effects of ICT usage (representing *second-order* effects) and systemic effects of ICT (representing *third-order* effects). Naumann et al. [2] claimed that a sustainable software product should have a low impact on *Sustainable Development*, and that the development process of the software product should be environment-friendly. This is reflected in the definitions of *Green and Sustainable Software* and *Green and Sustainable Software Engineering* that were provided. Green and Sustainable Software:is software that leaves a small footprint on the environment. Green and Sustainable Software Engineering is the art of defining and developing software products in a way, so that the negative and positive impacts on sustainable development that result and/or are expected to result from the software product over its whole life cycle are continuously assessed, documented, and used for a further optimization of the software product. The *GREENSOFT* model also supports different stakeholders of a software product in developing, maintaining, and using it in a sustainable manner. The model comprises four parts: *Life Cycle of Software Products, Sustainability Criteria and Metrics, Procedure Models, Recommendations and Tools*. Mahmoud and Ahmad [4] proposed a model for a green software engineering process consisting of two levels (described below). The first level comprises metrics for the green assessment of every stage in the software engineering process. The second level addresses the role of software itself in sustainable development and green computing. The model followed the definitions of Green and Sustainable Software and Green and Sustainable Software Engineering presented by Naumann et al. [2] and their definition of ICT impacts because they consider human and social sustainability issues. [4] also included an additional definition which is Green and Sustainable Software Process because their aim is to provide green instructions for the whole lifecycle of software production.

## First Level

The first level defines a software engineering process to mitigate the negative impacts of ICT on the environment. The process consists of seven stages of the software lifecycle: requirements, design and implementation, testing, green analysis, usage, maintenance, and disposal. In [2], the part of *Life Cycle of Software Products* discusses impacts of ICT on sustainable development in stages of the product’s lifecycle. However, they do not include the requirements and testing stages. These two stages were considered in [3] in contrast to many green software models. In addition, a green analysis stage was added to measure the greenness of the output of every stage.

## Second Level

Another idea missing from the *GREENSOFT* model [2] is the software’s role in reducing the negative impacts of ICT and improving sustainable development. The second level of the model presented by [3] describes how software can act as a tool to monitor efficient use of resources

# GREEN CLOUD COMPUTING

Cloud computing reduces power consumption by providing cloud applications with virtualized computational resources dynamically upon request such as virtual OS instances. This technique requires keeping idle VM instances in a queue as standby for any request. Consequently, 70-80% of power consumption in data centers is wasted [33-36]. In order to avoid over-provisioning of idle resources, auto-scaling technique was introduced to improve server utilization of resources and support greener cloud computing by allocating virtualized computational resources, dynamically and accurately, to cloud applications based on their current loads. The objective is to maintain the auto-scaling queue in a green manner while preserving QoS. However, determining the number of VMs to fill the queue and their configurations would be very challenging.

Dougherty et al. [7] describes a model-driven green technique for sustainable *auto-scaling* cloud computing infrastructures called *Smart Cloud Optimization for Resource Configuration Handling* (SCORCH)*.* The authors mention three main challenges of configuring VMs: The need for recognizing the VM configuration options of cloud applications and their constraints, the choice of VM configurations to be kept in the auto-scaling queue that can warrant a satisfactory QoS and the optimal auto-scaling queue size.

*SCORCH* addresses these challenges based on the following four functionalities: (1) Feature models [32] are used to represent VM configurations, implementation details. (2) Cloud applications are requested to inform *SCORCH* about the VM configurations that it will ask for. (3) Feature configuration problems are transformed into constraint satisfaction problems (*CSPs*) and an objective function is defined, to aid in deciding on the appropriate settings of the *auto-scaling queue*. (4) Optimizing the objective function yields an optimized the *auto-scaling queue*.

The greenness of *mobile cloud computing* is linked directly to the stability and efficiency of the wireless communications. Gai et al. [8] introduced a dynamic energy-aware cloudlet-based mobile cloud computing model (*DECM*) that takes advantage of cloudlets to reduce the amount of energy consumed by wireless communications. The main objective of the model is to provide green computing on mobile devices without affecting the *QoS* in cloud services. The nearest cloudlets receive requests from mobiles through the virtual machines corresponding to client applications. A cloudlet may switch a client’s connections to another one if it can provide better and greener service. Cloudlets are coupled with dynamic programming algorithms that enable them to find the most convenient cloud servers to connect with. The *DECM* algorithm is a minimizing algorithm for the cost of the wireless communications in *mobile cloud computing*.

Xu et al. [9] addressed the issue of VM scheduling algorithms that affect the efficient migration of virtual machines between nodes of the cloud. The authors presented a VM scheduling algorithm, *VMSAGE*, inspired by the physical gravitational effect, as an improvement of the simple scheduling algorithms. According to the physical concept of gravitation, the algorithm shuts down data nodes having a low utilization rate and migrates its VMs to other nodes with good heat dissipation in order to avoid overheating. The system decides which VMs will migrate before others based on initial speeds of migration. VMs with very high utilization rates, having large amounts of resources, or placed in servers with very high temperatures are assigned higher values of initial VMs than others. VMs are migrated to other servers that are selected based on lower costs of migration and heat dissipation. The *Cloud of Things* paradigm *(CoT)* was introduced to overcome the problems of limited storage capacities and computational capabilities in *IoT* devices. However, *CoT* was shown to be inefficient for applications that require high latency. *Fog Computing* was introduced by *Cisco* to support the provisioning of *IoT* applications by bringing computations towards the edge of the network. This technique has various benefits such as reduced energy consumption in data centers, and improved latency and network bandwidth.

Mukhtar et al. [11] presents a green strategy for allocation of application modules in fog devices. Its objective is to determine the best suitable place for offloading, in the Fog or the Cloud, taking into consideration energy consumption, CPU capacity, and desired response requirements (or tolerable delays). This approach was assessed by measuring energy efficiency in a remote patient monitoring system (RPM) and comparing the results with those of two other approaches. The results show that the proposed approach reduces energy consumption.

# GREEN MOBILE DEVELOPMENT

In [16] different perspectives to study energy consumption on mobile devices were discussed. A first approach is from the perspective of instructions processed by the Central Processing Unit (CPU). Whenever the amount of code or data the system needs to fetch from the cache increase, the energy consumption will eventually increase as well. Another approach is from the network perspective. For example, using 3G network connection consumes more energy than using 2G network connection. The last approach discussed was from the application perspective. Two factors were addressed in this section: (1) Bluetooth usage and (2) the SMS message size. It was proven that using the mobile with Bluetooth enabled consume much more energy than using it with Bluetooth turned off. Regarding the SMS message size, sending multiple SMS messages of smaller size will consume more energy than concatenating these messages into fewer SMS messages but of larger size.

In [17] some actions were recommended to save energy. The first recommendation was for mobile applications to operate in networks that offer best-cost benefit rate. For applications that are used to send data (e.g. email applications), consider the alternative of delaying the sending of data, so that the maximum number or requests can be triggered at once. Moreover, applications must make use of parallel connections to transfer data, a strategy that would save a lot of energy. In [17] a mobile computing prototype called GMECloud that utilizes energy efficient mobile devices (e.g., smartphones and tablets) as computing resources is proposed. The mobile client’s application checks the status of the device, if the device is ready, it connects to the server. The status of the device is defined in terms of different characteristics, for example, the CPU usage, the device battery level, etc. The server splits the job into smaller tasks; these tasks are then distributed to multiple clients. If the number of active clients is high, the server will assign to each client fewer tasks. This means that the time required by each client to finish the assigned tasks will be less.

In [15], a novel approach is proposed where Middleware is coordinating between mobile and cloud computing techniques to achieve green computing for next generation. The major approaches of the Green Computing are Product longevity, Software and deployment optimization, Power management, Materials recycling, Telecommuting and Low performance computing. A middleware is a software infrastructure, it binds together the applications, operating systems, network hardware, and network stacks. Its major task in this proposed architecture is to evaluate Data center power, Operating system support, Power supply, Storage, Video card, and Display. Green Cloud Computing System Architecture Technologies consist of five core technologies: Scalable Network Architecture, Energy-efficient, Cooling and Power Efficient System, Modular Cloud, Computing System, Scalable Virtual Internet Appliance and Flash Memory Based Cloud Storage System. In [37], the main concern is to highlight the energy related issues as early as possible in the software development life cycle (SDLC) of an application making it more energy efficient and reducing the cost regarding energy consumption. This paper divides the green technology, as mentioned before, on all the stages of the software development life cycle (SDLC) of a given application. It starts with **Green software requirement specification**, means that there may be additional software requirements to maintain the developed software. Next, **Green Software design**; the main concern of the software developers is always the software structure, the modules needed, the software architecture, etc. While energy efficiency is a main part for a good software design, it’s rarely taken into consideration by software developers at this stage. Moving forward, **Green Software Implementation** focuses on reducing the application CPU consumption, the number of parameters used, and many other factors that affect the energy consumption. Regarding the testing phase, a **Green Software Testing** takes into consideration the number of people and the amount of equipment allocated to test the energy used by the application, of course based on predefined test cases related to energy consumption. Finally, **Green Software Maintenance** tends to perform regular maintenance tasks that will keep data transmission at optimal efficiency.

# GREEN DATA CENTERS

## How Green Is a Data Center

Before taking a risk, an industry must first study the level of energy efficiency which is the level of energy consumed by the industry. Based on the quantitative results that issued from energy efficient measures we can decide what suitable techniques we can use in order to turn the data centers to become ecofriendly. In [23], Mata-Toledo and Gupta mentioned two important metrics which are, the Power Usage Effectiveness (PUE) and Data Center Efficiency (DCE). They mentioned too an aid to the following analysis such as tools known as the “The Green Report”. However, Siso et al. [38] focused on metrics technique called CoolEmAll that focuses not only on Energy consumption but also on Heat-aware metrics. They pointed out, that the reason they introduced CoolEmAll metrics is because of the reason that standard metrics such as, CFD, PUE doesn’t allow any space for predication of energy performance to enhance the energy efficiency. CoolEmAll provides analysis tools for data centers efficiency according to IT equipment. Moreover, Wang, Khan [39] presented in their study more metrics in order to measure the consumption of energy performance in data centers. The aim of their study is to know how green a data center is through different matrices and measurements and according to that information possible techniques can be taken for a data center to go green. They pointed out that there are two methods for going green either to involve green requirements into building the infrastructure of the process or to green up the process of a working data center in every day usage.

## Optimization Methodologies

Moreover, after measuring the efficiency of a data center in an industry, there must be certain measures taken in order to come up with an ecofriendly data center. In their study, Sari and Akkaya [40] mentioned that one of the greatest threats that affect green data centers can be divided into two groups. First threat, consists of the in ability to manage the cost crises that is born due to the divergence in determining the efficiency performance technique from one hand and the calculating the performance of the server. Another threat relates to data centers is the release of carbon dioxide that results from data centers to the atmosphere. The authors presented two methods of techniques into data centers to handle these threats. They first presented cooling method know as liquid cooling approach that is put into action its only limitation is that it is geographically dependent which means it must be located in cold areas so that cold water is formed that will reduce temperature and hence reduce the consumption of energy. Another cooling approach is known as direct cooling that is responsible for reducing energy consumption. In addition, another technique is presented that relates to using energy efficiency servers which are achieved by using renewable energy resources to power up the data centers. Another way to produce efficient energy that was provided in this study is either to use of virtualization software through virtual machine. Furthermore, Ghani, Nikejad, Jeong [22] presented in their paper a series of techniques that enables a data center to go green by saving the consumption of energy. They managed to divide their field of work into four fields by presenting energy saving techniques for servers, energy saving techniques for networks, energy saving techniques for a combined environment of servers and networks, and finally by energy saving techniques by using renewable energy. As for servers, it’s known that server is the main consumer of energy in data center so establishing power saving environment is vital in this area and it is covered through methodologies such as, server virtualization that tends to minimize the number of hardware in use and decrease the amount of functioning servers through making more than one virtual machine on server. Another technique known as dynamic power management that handles to puts down the computing servers when they are not. A third technique known as dynamic voltage scaling that sets the CPU power according the level of load. Ghani et al. managed also to cover techniques that help to reduce energy consumption in networking fields due to that fact that networks infrastructure is the second consumer of energy after servers by utilizing 30% of energy used for powering data centers. One of the techniques is known as sleep mode that manages to switching of the networks resources or putting them to sleep mode whenever they are not in use.

# GREEN COMPUTING IN EDUCATION

Many work and studies have been made in order to improve the green computing awareness and practices in the education sector.

## Awareness on Green Computing in Education Sector

|  |  |
| --- | --- |
| **Measure/Technique** | **Source** |
| **Online Learning:** reduce the pollution that results from students and faculty travels by adopting online learning techniques such as video conferencing and web conferencing.  **Implementing Green Computing in administration and in sharing information:** use of online examination systems instead of paper-based exams, using software application to submit student information such as grades and attendance, reduce the use of papers by introducing online applications, forms and petitions, introducing online system for fees payment, use of online brochures thus saving papers and conserving power.  **Saving electricity:** educational institutes should consider the huge power consumption that result from the use of computers on its different offices and classes. ENERGY STAR labeled computer equipment should be purchased and should replace energy inefficient equipment (e.g. LCD monitor instead of CRT one) | [46] |
| **Upgrading Computers:** upgrading specific components (CPU, system memory) in the computer in order to prolong the lifecycle computers and improve performance.  **Power saving modes:**  computer power consumption can be managed in an efficient way by using the most “green” and efficient computer power saving mode. Different modes include sleep mode, hibernate mode, system standby mode and hard disk sleep mode. The Hibernate mode proved to be the most effective among other as it power off the computer completely.  **Eliminate Phantom Loads:** by using of power strip devices that power off in an automatic way powered off devices that are plugged into the strip. | [47] |
| **Virtual Desktop Infrastructure (VDI):** exploiting the green benefits of virtualization (operation efficiency, compatibility, ease of management, simplicity of deployment, low carbon emissions etc.) by implementing VDI in educational institutes. The implementation of VDI has proved to be power efficient as it saves power and consumes low energy compared to non-virtual infrastructure. | [48] |

The awareness and knowledge of green computing have been addressed by different surveys and studies where different target groups were surveyed [42, 43, 46, 28]. Many studies were conducted in the literature to comprehend the level of knowledge and awareness of green computing among university students [27, 44, 30]. In [27], Dookhitran et al. conducted a study to check the level of awareness of green computing among students in the University of Technology in Mauritius. The survey was designed for students of the School of Innovative Technologies and Engineering. The main goal of the study was to check and analyze the level of awareness of green computing focusing on student’s computing related activities and their computer literacy. The survey questions focused on the hardware aspects. Findings showed that students, in majority, are computer literate but they lack knowledge of some major green computing practices (e.g. screen savers.) In [44], Selyamani and Ahmad conducted a study that addressed the student’s awareness of green computing issues in higher education institutes focusing mainly on hardware aspects. The survey was undertaken by students from Higher education institutes in Malaysia. The study findings indicated that students, mainly non-ICT, lack the green computing knowledge. In [30], students and academic staff at Botho College in Botswana were surveyed in order to check and measure the levels of awareness regarding green computing and the negative influences of IT on environment. The study was also conducted to check if any green computing policies are established in the institution. Interviews with staff of the IT department were also prepared and organized. The results showed that the level of awareness regarding green computing is low, and that no green computing policies are set in the institution. Furthermore, findings indicated that changes in behaviors and use of technology and IT can be reached by exalted education.

## Approaches to Create and Raise Awareness

Figure 1: An overview of some green computing measures to be used by educational institutes

The topic of creating and raising awareness in the education sector has been studied in the literature where different and many ideas have been published. According to [30], creating a website that contains different green computing information, procedures, policies and tips is one solution to create awareness among students in a university. Pang et al. called for the extending the aspects of green computing in the educational programs [41]. Dookhitram et al. proposed that environmental IT information can be spread by the information channels that are mainly used by the students [27]. Haraty et al. suggested engaging students in educational activities and including awareness campaigns in the educational curriculum [26]. In [45], Suryawanshi presented a number of techniques that raise the awareness of Green ICT such as: Including an obligatory green ICT program course in all universities, to train learners about the importance of implementing green practices by starting Green Computing Certification course, to present rewards for educational institutions and educators (Green Institute, Green Teacher) that best embrace green practices efficiently as a motivation, effective promotion of green ICT practices, and encouraging faculty and students to choose webinars instead of traveling and adopting online education mechanisms in universities that will lead to less carbon footprint [45].

## Green Computing Techniques to be used by Educational Institutes

A lot of studies have been conducted and ideas have been published in the literature about the measures that needs to be taken by educational institutes in order to improve the practicing of green computing [46, 47, 48]. An overview of some measures is provided in Figure 1. Many work and studies have been made in order to improve the green computing awareness and practices in the education sector. However, more green awareness should be raised among students. Educators and educational institutions have a crucial role to play in order to promote and spread green computing awareness among students. Moreover, many measures should be taken and many techniques should be used in order to practice real green computing in educational institutes.

# CONCLUSION

Technology has become a major cause for global warming whenever treated inefficiently. A huge urge is needed to save our environment before it’s too late. In this paper, we went over different approaches to “GO GREEN”. We also addressed the software engineering models for green computing, and the four different perspectives for this topic: Green cloud computing, Green mobile development, Green data centers and the importance of green computing in educational sector .The usage of green computing by normal people contributes to their harmonic existence in knowledge society, and this corresponds quite well to basic objectives of cognitonics [49,50]. To sum up, this paper is intended to be part of the research that have been ongoing to increase the awareness of people towards this topic and presents different approaches that will help whenever applied in software development.

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