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GREEN COMPUTING: LATEST PRACTICES AND TECHNOLOGIES FOR ICT SUSTAINABILITY

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Abstract:
In terms of growing awareness about environmental impact of computing, green technology is gaining increasing importance. With rising energy consumption, global warming and e-waste, the idea of green computing is widely taken into serious consideration by both the government agencies and private companies, as their contribution in good practices for sustainable development. Green computing refers to the practice of environmentally responsible and efficient use of computing resources while maintaining economic viability and improving its performance in eco-friendly way. This paper aims to present main approaches and assumptions of green IT by showing the latest solutions and energy efficient practices in computing industry. In the article author has made a systematic study on several strategies and developments in context to the ICT sustainability as a future asset of growth for modern society. The article focuses on the practices like use, disposal, design and manufacturing as well as on technology based-solutions like electronic products and services e.g. green cloud. The outlook for greener ICT should include using the Internet as a powerful agenda for promotion and education for environmentally aware behaviour and as a useful tool for creating eco-friendly technology.

Keywords: green computing, power management, sustainability, eco-friendly technology, green cloud

1. INTRODUCTION: MAIN GREEN COMPUTING APPROACHES AND SOLUTIONS

Green computing is the term referring to efficient use of resources in computing and IT/IS infrastructure. Efficiency of green computing emphases on minimalizing hazardous environmental impact in conjunction with achieving economic viability and improved system performance. The field of "green technology" covers a board spectrum of subjects – from alternative energy-generation and electricity consumption techniques and use of eco-friendly, recyclable materials to implementing sustainable digital services. Technical issues of green technology includes: *green infrastructure* (energy-efficient buildings, intelligent cooling systems, renewable power sources), *green hardware* (multicore computing systems, energy efficient server design and solid-state storage and *green software and applications* - parallelizing computational science algorithms to run on modern energy-efficient multi-core clusters, intelligent load distribution and CPU switch-off (Snell, Weinberg, Katz, Yun, Wilson, Narayanan, Mo, Calzetti, Moss, Shenoy, Weems, p. 1).

Nowadays in order to achieve social awareness and promotion of green technology solutions, main four complementary approaches are employed:

- *Green Use:* Reducing the power consumption of computers, information systems and their peripheral subsystems in environmentally friendly manner.
- *Green Disposal:* Refurbishing and reusing existing old computers and other electronic associated devices. Recycling unwanted used computers and other electronic-waste by IT vendors using their "take back" policy in order to take responsibility for the full lifecycle of products they produce.
- *Green Design:* In broader aspect connecting companies, government agencies and environmental organizations in order to develop inventive management, business and regulatory processes that can improve environmental quality while enhancing economic development ==. In narrow and practical aspect designing power efficient and eco-friendly computers and its subsystems like servers and cooling equipment.
- *Green Manufacturing:* Process of production of computers and associated devices include methods of manufacturing and biodegradable components for minimal or no impact on environment. This approach allows to provide economic benefits like long-term cost savings, and business process efficiency improvements.

These four approaches cover a number of areas, efforts and actions for efficient use of computers and computing, however the basic problem occurring from this issue is finding the path for achieving sustainability. "Development that meets the needs of present without compromising the ability of future generations to meet their own needs" – that's how the sustainability is defined by WCED in 1987.

Computer manufacturers and vendors contribute directly to pollution, whereas the IT industries have a hidden impact on environmental pollution caused by unconscious consumption of power and inefficient use of hardware devices (Agarwal, Datta & Nath, 2014, p. 5). The ICT industry is responsible for about 2% to 2,5 % of all world's greenhouse gas emissions. Although it is not a large percentage, very disturbing is fact, that the rate of ICT consumption is increasing by 20% a year so if nothing is done the contribution to global greenhouse gas emission is projected to nearly double – to about 4% - in 2020. Hence, there is a necessity to balance the dramatic growth of utilizing computing resources with green technology to reduce environmental impact at the same time maintaining overall development. The need for green computing is obvious, if world is determined to pursue the assumptions of sustainability. Modern IT systems are based on a complex mixture of people, networks and hardware. Green computing initiative must be structured in nature and turn in the direction of the increasing number of sophisticated computational problems. The elements of such solution may contain such issues as:

- End-user satisfaction which means improved system performance and use while regarding social and ethical responsibilities and awareness.
- Restructuring management.
- Reducing and removal of electronic waste.
- Virtualization of server resources.
- Efficient energy consumption.
- Replacing personal computers with energy efficient thin clients.
- Return on investment.
- Designing energy efficient chips and disk drives.

- Telecommuting and remote computer administration to reduce transportation emissions.
- Reducing transportation costs by supporting team work and meetings thus minimalizing the co2 emissions (less vehicle and air business travel).
- Providing information and promoting green manner.

This paper mainly focuses on aligning ICT processes and practices with the principles of sustainability and finding innovative, alternative ways to use ICT across the enterprise and beyond, to deliver environmental benefits.

1.1. Green manufacturing

In order to achieve goals set by the idea of ICT sustainability whole process of creating ICT infrastructure should be taken into account. Minimal impact on the environment should be one of the key assumptions for IT manufacturers during the process of design and production of all ICT components. Major IT companies are already applying green standards to their own operations in order to: gain new revenue opportunities and promote social and environmental responsibility influencing customers and market competition (Gupta, 2013, p. 3). Main areas in green manufacturing of computers are:

- *Eco-friendly design:* the design of computing resources that meet the stringent restriction of e.g. *Energy Star* enabling further utilization with determined power supply and power management requirements (including special modes and allowances). "The *Energy Star* devices can be programmed to power-down to a low electric state when they are not in use, helping to save energy and run cooler which helps them last even longer" (Kiruthiga & Vinoth Kumar, 2014, p. 6319).
- *Use of bio-products:* biodegradable and renewable materials often requires less energy to produce in comparison to traditional toxic materials. Manufacturers use many different types of plastic in computers, which makes is very changeling do recycle. What is more computers contain hazardous contaminants for environment like: cadmium, lead, mercury or chromium. Use of harmful power-demanding materials can be replaced by efficient and recyclable elements e.g. displays made of OLED's (Organic Light-Emitting Diode) - in manufacturing mercury is not used, making them more environmentally friendly.

1.2. Green use

The great importance is to understand the full life cycle of computing resources, while applying the idea of green computing. Following are the areas and practices that users can implement for maximizing usefulness and minimalizing negative consequences for environment:

- *PC power management techniques:* set of actions and mechanisms for controlling the power use of personal computer hardware mainly turning off the power or switching the system to the low-power state when inactive (Wikipedia). In computing this kind of power management is built around the specification called The Advanced Configuration and Power Interface (ACPI), an open industrial standard that allows direct control, management savings energy by the operating system - automatic switch off your monitor, go to stand-by mode, etc. In addition, the system can go into hibernation, at the time the CPU and RAM are disabled. Some software solutions allow the definition of voltage e.g. on CPU, which allows for the reduction of heat production and energy consumption. Some mobile processors can adjust the voltage up to the required capacity in a given moment. This technology is called *SpeedStep* on Intel processors, *PowerNow!, Cool'n'Quiet* on AMD chipsets, *Longhaul* on VIA processors and *LongRun* of Transmeta processors.
- *Virtualization:* In the traditional IT infrastructure servers are dedicated to specific computing functions like storage, communication, database and so on. Virtualization eliminates the need for a dedicated server to run applications – it enables at the same time to run multiple operating systems on the same hardware platform and the system at maximum possible performance (Grzadziel, Kosek, p. 4). It is based on a launching the operating system in virtual machine, abandoning the universality of emulation many computer architectures. Limitation only to the hardware platform used to perform a certain number of guest operating system processes (emulated system) directly on the hardware of computer. Only when such operations are not directly performed, virtualizer emulates them. This means that a virtualizer starts the operating system so that it can coexist with the primary system and achieve maximum compatibility and performance. The dedicated servers are only used when there are

active connections, they can be used for other purposes during their idle or inactive time or use (Raj Gowtham, Ghayathree, Venkata, 2011, p. 3). Virtualization contributes in green technology on the one hand by reducing: number of servers, power and disposal requirements of desktops and limiting costly business travels of staff, customers and suppliers as well as replacing paper systems with on-line communication platforms (Warnaweera, 2012, p.45).

1.3. Green Disposal

The approach of green technology disposal include refurbishing and reusing old existing computing equipment and proper recycling of obsolete, unwanted or broken computers and its subsystems. Due to strength of negative effects on environment arising from improper approach to disposal, this aspect of green computing is among one of the most important:

- *Reuse:* Even old computer should continue to be used as long as it meets the requirements of user. Computer systems which basic functions are obsolete and fail to meet the holder's need can be given to someone who want to use it or need it for its functional components. Many charities and non-profit organizations are willing to receive old equipment through donation to re-purpose or utilize its particular function. Prolonged use of a computer system significantly contributes to the reduction of negative environmental effects.
- *Refurbish:* By reconditioning and replacing IT hardware parts user can prolong its utilization. Old equipment can be restored in order to maintain its functions, it also can be up graded for obtaining new serviceableness. Reasons of such actions can be motivated by lower cost of refurbished equipment – nowadays more enterprisers are willing to buy restored hardware, and such market is growing (Saha, 2014, p. 48). At this point it is important to understand the difference between "refurbished" and "used" product. Refurbishing gives the guarantee that the product was tested and verified to function properly while "used" products may or not may be defective (Raj Gowtham, Ghayathree, Venkata, 2011, p. 3). Hardware vendors often resell equipment that was returned under warranty after repairing the defects and checking proper function. Refurbished hardware provide a cost-effective alternative. Another incentive may be maintaining corporate standards by ensuring that all employees use the same equipment. Such action significantly reduce e-waste.
- *Recycle:* Recycling is one of the most complex methods of environmental protection. Its aim is to reduce the consumption of natural resources and reduce waste. The principle of recycling is to maximize re-use of materials, taking into account minimizing the expenditures for their processing. This principle allows to protect both: the raw materials necessary for manufacturing as well as those required in the further processing. Recycling takes place in two areas: the production of products and the subsequent wastes formation of these goods. Recycling assumptions involve forcing appropriate attitudes among goods manufacturers, favouring the production with the most recoverable materials and creating the appropriate behaviour of the recipients of these goods. E-waste from computer and associated equipment contains different substances, many of which are hazardous, such as mercury, cadmium, lead, arsenic and chromium. The health effects of these toxins on humans include birth defects, brain, heart, liver, kidney, skeletal, reproductive and nervous system damage (Agarwal, Basu, Nath, 2013, p. 297). If computers are thrown out on the landfills and other improper locations, toxic chemicals can be released into the environment (food chain and water). Burning e-waste is another threat – causing release of a toxic gases into the air that we breathe (Saha, 2014, p. 48). Although e–waste mainly contains harmful materials, some valuable metals like gold and copper can be found and become source for secondary raw materials. Such actions can be turned into profitable business.

To sum up: "manufacturing and purchasing of energy efficient IT infrastructure, the efficient operation and utilization of computing devices as well as its proper disposal i.e. green manufacturing, use and disposal are the efforts that lead to economic and ecological benefits" (Gupta, 2013, p. 4).

2. LATEST DEVELOPMENTS

2.1. Green Cloud Computing

The Gartner report from May 2009 defines cloud concept as "a style of computing where scalable and elastic IT capabilities are provided as a service to multiple customers using Internet technologies". The

use of the potential of cloud computing model interacts with the concept of sustainable development, understood in three dimensions: economic, environmental and social. Clouds consolidate environment, saving power, cooling, space and money. Cost savings and flexibility of operations are among the most frequently mentioned benefits associated with a decision to adopt the cloud computing solution. Fixed costs related to the investment in infrastructure (which in the traditional business model generally increases with time and the need to update the software) are reduced, as well as energy costs feeding the infrastructure. Traditional costs related with the licenses, number of users, equipment, operation, repairs and applications are replaced for payment for functionality that is actually used by the company or other organization that also obtain access to the latest technology. This solution allows to adjust supply to demand, eliminating incurring unnecessary costs associated with the overestimation or underestimation of customer needs. At the same time, it affects the reduction of occurrence of lost sales opportunities risk and cost of incorrect demand forecasting and company's supply planning.

Some aspects of cloud's ICT infrastructure allow to identify the model as the one providing green benefits. The basic features of the model allow you to specify a number of environmental benefits that can be achieved by migrating the IT resources to the cloud. These aspects may include:

- Dynamic provisioning and multi tenancy: lower energy consumption and associated carbon emissions than the traditional approach of over-provisioning (Pooja Kallange, p. 27). Automatic processing of computing environment supports user needs, operating under the cloud may acquire or release the resources (instances) where it is appropriate (according to the demand). Dynamic resource allocation is done automatically, thus datacenters maintain active servers according to current demand. With virtualization technology, which allows to connect disparate resources in one great set of resources it is possible to release them more selectively to all customers at the same time increasing the level of their use. Without virtualization cloud computing would never arise. The entire pool is shared by many customers of a one supplier, in the way of dynamic allocation and releasing precisely defined portion of virtual resources. Level of use of the pool is proportional to changes in demand for computing resources.
- Optimal server utilization: traditionally, many servers remain idle of 85-95% of the time using nearly as much power as they do when they are active. Virtualization technology enables hosting of multiple applications through one server. The number of active servers is reduced and the power consumption is lower.
- Energy-efficient client devices: the public cloud model reduces the number of energy consuming clients through small energy-efficient devices (e.g. thin clients)

2.2. Carbon aware green cloud architecture

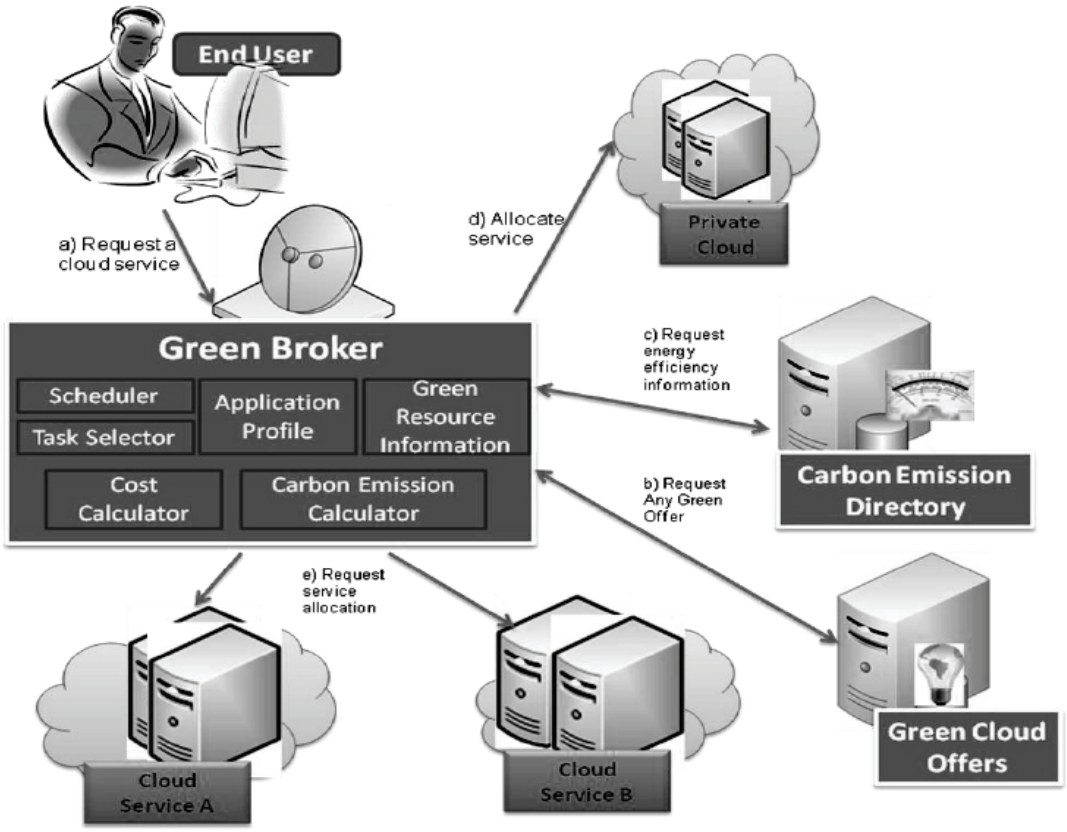
Green cloud architecture is one of the latest developments of green computing idea. The aim of this unified solution is to deliver both users and providers, high-level architecture for supporting energy-efficient service allocation which is based on cloud technology. Cloud providers, being profit oriented are looking for solutions which can lower their electricity bills without losing their market share. The goal of satisfying the demand for high-level computing services on the users side and saving energy on the providers side, can now be achieved by implementing the green cloud infrastructure.

Figure 1 shows the architecture for supporting energy-efficient service allocation in green cloud computing infrastructure. The cloud services (SaaS, PaaS, IaaS) are registered in the form of public offering in Green Offer Directory. The Green Broker has the full access to all services which are available and registered in public directory. Green Offer directory is incentive for the providers who, list their services with discounted prices and green hours. A typical cloud broker lease cloud services and schedule applications Green broker's responsibility is to select these offerings in terms of requirements of end user. Each request is analysed according to the price, time and service that offer the highest quality and least CO2 emission. Green broker uses the up to date information about cloud services and current status of energy efficiency parameters using Carbon Emission Directory (CED) which is very important component of the architecture. CED may include some the crucial green metrics power measurement like: Power Usage Effectiveness (PUE) – which is the fraction of total energy consumed by the service of a data centre to the total energy consumed by IT equipment, some cooling efficiency indicators like Water Usage Effectiveness (CUE) – which is the calculation of greenhouse gasses (CO2, CH4) release on atmosphere by the data centre (Atrey, Jain & Iyengar, 2013, p. 96) and carbon footprint. Using data stored in CED and green offer directory broker is able to:

analyse user requirements, calculate cost and carbon footprint of services and finally perform green aware scheduling.

In general green cloud framework enables end user to access to all three types of cloud services through one of the deployment models: private cloud (hosted and operated internally within and by a single organization), public cloud (computing resources are shared by several subscribers via Internet in a pay-as-you-go manner) or hybrid cloud (the organization stores and processes critical data in-house in a private cloud and non-critical data is outsourced to the public cloud when needed), (Yeboah-Boateng & Cudjoe-Seshie, 2013, p. 705).

Figure 1: Integrated carbon aware Green Cloud Architecture



Source: Kumar Garg & Buyya, 2012, p. 20.

2.3. Data Center sustainability improvements

The rising energy costs, desire to make existing investments more and more profitable are making today's cloud providers to implement best practices to make datacenters operation green. To build eco-friendly data center, several best practices in key areas has been proposed for improving sustainability:

- Proper location which allows clean energy consumption through renewable sources (solar energy generation, wind power generation, fuel cells, cogeneration).
- Cooling system (new systems based on liquid cooling, nano-fluid cooling systems, and in-server, in-rack and in-row cooling by companies such as SprayCool; free cooling, spot cooling, using cable grommets to reduce cool air leakages).
- Building design (heat insulation, optimizing floor layout, recycling water)
- ICT platform (middleware-facility linkage, dedicated racks & servers, virtualization technologies).
- Deployment of newest power efficient servers and processors (Kumar Garg, Buyya, 2012, p. 17).
- Energy linking (power sharing between company centers, locating data center near power station).

2.4. Solar Computing

Nowadays solar power in gaining more and more attention throughout the world. Solar energy is power derived from the sun through the use of solar panels. Good example of powering PC's with the sun is Taiwanese manufacturer VIA Technologies Inc. VIA Solar Computing initiative is a part of VIA Green Computing projects. VIA Solar Computing use advanced, cost-effective solar panel technology in cooperation with Motech Industries – one of the largest and leading solar product manufacturers and innovators. Solar cells combined with VIA processor platforms and system technologies developed complete solar-powered computing solutions that are less polluting, more affordable, more reliable and more flexible for a wide variety of new markets, applications and environments. VIA Solar Computing is focusing on photovoltaic (PV) solar power to take advantage of the numerous benefits for both emerging market and urban computing installations:

- Solar power is clean non-polluting energy.
- Once capital costs are covered (like purchasing and installation) solar cells require very little maintenance, hence in further perspective of time they provide energy at virtually no cost (Lakshmi, Lalita Sarwani, Nalini Tuveera, 2012, p. 1284).
- Solar panels are silent in operation.
- Solar panels do not require refuelling; they are self-sufficient.

Due to the undeniable benefits of renewable energy in the form of solar energy private companies continue to invest in research and development of this kind of power providing. This solution is not the cheapest however leasing is common way to go solar today (Irshad Shiddiqui, 2013, p.53). At the same time, governments are starting to recognize the benefits of solar power, with many now offering tax and rebate incentives to promote this clean energy.

2.5. Telecommuting

Telecommunications-related technologies, such as teleconferencing, also are often implemented in green computing initiative. "Advances with communications devices and with the aid of computer networking systems have made it possible for people to work from remote locations and for telecommuting to become an ever-more feasible option for many companies. With the aid of telecommuting it increased satisfaction between the two parties, reduction of greenhouse gas emissions related to travel, and increased profit margins as a result of lesser costs for workplace space, heat, lighting and many more. This technology is currently running in taking green computing initiatives" (Lama, Sharma, Goyal & Singh, 2014, p. 972). Through IT/IS systems telecommuting can also be used for remote administration, group document management and cooperative knowledge management. It is estimated that one-fifth of all travel is associated with commuting. Thus, the wider use of teleworking would greatly reduce the negative impact on the environment. Unified Communications leads to an increase in the level of cooperation between employees. Video solutions enable real-time collaboration which is one of the most important environmental initiatives in the business environment.

3. CONCLUSION

Challenges of sustainable development met by today's businesses operators at the same time forcing their activeness not only in economic, but above all, environmental aspect. Computers and related infrastructure (e.g. data centre) are not only costly to maintain, but also harmful to the environment due to the carbon emission. Nowadays, with a greater concern for the environment, green computing reduces the negative effects of ICT on sustainability. This solution protects the environment by dealing with the power management techniques, saving electricity and reducing e-waste. Paper summarized some of the useful practices and has given leads for optimised utilization of newest technologies. Green computing is not only manufacturing, using and destroying the computers in environment friendly way, but also exploiting existing computing resources in more efficient way by implementing new concepts like green clouds. Cloud providers need to reduce the electricity demand of clouds and take major steps in using renewable energy sources rather than just looking for economic incentives like cost minimization. Green ICT sustainability addresses issues such as: using renewable energy sources to power data centres, reducing e-waste, designing energy efficient hardware, middleware and software, running multiple operating systems via virtualization, providing information to customers in order to encourage them

make green choices, reducing transportation cost and emissions by telecommuting (Kevin, Muketha, Kamau, Wanyembi, Titus, 2014, p. 200).

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