Green IT for Innovation and Innovation for Green IT: The Virtuous Circle

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Abstract. Green IT has recently appeared as a mandatory approach to take into account energy efficiency in information technology. This article investigates the Green IT area and its opportunities for innovation. This chapter analyses the main motivations for Green IT, and proposes a definition of Green IT including social, environmental and economic concerns. Beyond simply listing areas of possible innovation, this paper studies the virtuous circle that appears in Green IT: while Green IT has its own motivations, the resulting research feeds into other research fields. Innovation in this particular sector paves the way for further innovation by means of original research not foreseen initially.

Keywords: cooling, energy efficiency, green IT definition, innovation, virtualization.

1 Introduction

Until recently the ecological impact of the usage of IT was not a subject of discussion compared to reliability, performance or quality of service. Since some alarming studies were conducted around the world [1], [19], [20], governments, funding agencies and industries saw the tremendous impact of IT in both economic and ecological terms and started funding efforts to push innovation in the sector of Green IT. Researchers in the public and private sectors, driven by sustainable consciousness (i.e. partly economic, ecological, political, and societal incentives) have proposed a number of technological solutions to cope with the problem, and have actually managed to reduce effectively part of the IT impact on the Earth.

In this paper, after analyzing the definitions of Green IT and the motivations for going green, we study the virtuous circle between innovation and Green IT. We argue that Green IT is nowadays a motor for innovation which is by itself preparing the ground for Green IT research for the next decades. The paper is organized as follows. Section 2 presents definitions of Green IT. Section 3 focuses on the motivations for Green IT. Section 4 proposes a final definition of Green IT. Section 5 analyzes two sources of Green IT innovation: server virtualization and hardware cooling. Section 6 concludes this paper and presents some perspectives.

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2 Defining Green IT

Numerous definitions of Green IT have been proposed in the scientific and public press for the past five years, taking into account several aspects. Without enumerating all the definitions, we propose in this section to analyze their main differences and approaches; this will help us to propose our definition within the scope of this paper.

IT Wissen [9] defines Green IT as “a movement coping with the increasing ecological awareness and representing the development of environment-sparing hard- and software and for energy saving technology”. This definition reflects that about 75% of German companies have some Green IT regulations, but mainly takes into account ecological aspects and neglects economic effects. In this definition, costs for servers and laptops, for instance, do not appear, while in reality these are important investments which appear in the financial statements of a company. It is quite striking that only hardware and software are covered.

TecChannel [7] gives the following definition: Green IT is “[e]nergy saving in server rooms due to an optimum of energy management”. TecChannel confines Green IT in its definition to electricity saving in server rooms. This point of view is quite remarkable. Firstly, electricity saving in server rooms is only one – and not even a very precise – description of several environmentally-friendly actions. Another such action would be to manage the load of the servers in order to maintain the same service for the consumers, users, besides saving energy. Secondly, IT cannot be only reduced to server rooms as it is in this definition. For example, personal computers in almost every private household are neglected. Looking to statistics [13], over 80% of private households own a computer. Also notable is that the ecological motives of TecChannel are not explicitly mentioned.

But IT is more than this. Lorenz Hilty [8] gives a definition of the life cycle: there is the use phase, the production phase, and the end-of-life treatment. Green IT can be employed in each stage to reduce the ecological damage. In this definition of Green IT, the costs of production are not mentioned – the real costs but also the “costs” for the environment, which we all have to pay-in reality only the producing countries, on a closer examination the people producing the servers or components and living in these areas, have to “pay” for the erroneous trend.

Green computing or Green IT refers to environmentally sustainable computing or IT. In [5], San Murugesan defines the field of green computing as “the study and practice of designing, manufacturing, using, and disposing of computers, servers, and associated subsystems – such as monitors, printers, storage devices, and networking and communications systems – efficiently and effectively with minimal or no impact on the environment”.

The Wikipedia [6] definition of the term is worth a mention: “The keyword Green IT (rarely Green ICT) is understood as an effort to create the usage of information technology alternatively information- and communication technology through the whole life cycle in an environmental friendly and resource conserving way; starting from the design and ending up with the disposal and recycling of the device”. This definition is, in comparison with the previous definition, rather general and global. It takes into account the whole life cycle of information technology, starting with the construction until the disposal, and is not only limited to the usage. It is positive that the resources are mentioned, although a list of resources would be desirable. However, the incentives for the efforts of Green IT are not listed in this definition.

These definitions show there are various ideas about Green IT. One reason might be that the whole IT area is quite a young topic of research and usage. Fifty years ago, the number of information technologies was so low that the impact on the environment was insignificant. However, in 2008, 95% of the companies in Germany and 75% of the private households had Internet access. In other words, there is a clear trend of a continuous rising in the use of information technologies [4]. Consequently, the greater the number of IT devices, the more they become an essential part of our lives. The interests of users and companies are therefore dynamic and are changing accordingly. As an example there are the rising costs of electricity in companies for additional equipment. This aspect was understood by companies and they started setting up some measures – mainly under the financial focus.

These measures, not only with the same effectiveness, addressed mainly energy reduction in order to reduce costs. Later, they were summarized under the definition Green IT. It has to be noticed that these thoughts were concretized principally during the last years and, during this time, even more companies were considering Green IT measures. This is making it difficult to find and to maintain a single, definitive definition of Green IT under such changing influences.

3 Motivations for Green IT

3.1 Ecological Reasons

Mainly because of the title "green", the first associated reason for the usage of Green IT is ecological. The following reasons do not only apply to IT but also to other areas such as the car industry. The following reasons do lead the end users and producer to an ecological awareness.

It is common knowledge that carbon dioxide (CO2) emission caused by humans is boosting the natural greenhouse effect and is thus causing global warming. IT is participating in CO2 emissions. Worldwide, the carbon dioxide emission attributable to IT is an estimated 600 millions tons, still growing up to 60% more by 2020. This fact is explainable by the high consumption of energy during the life-time of IT. The lower power requirements of Green IT could reduce energy consumption, which would lead to the decrease of CO2 emission of the production of energy.

The environment is mainly polluted during the production of information technologies. Many computers are as an example produced in China under inadequate ecological conditions. According to Hilty [8], the ecological damage that occurs through the production of a computer in China is almost the same as the ecological damage of the use of a computer during six years in Switzerland.

Figure 1 illustrates this statement. There are three stages of the life cycle in IT. It is remarkable that the ecological pollution during production has the highest impact. The production marks the ecological damage for the environment, but additionally for the worker, as well as for the residents around the production centers. For the production of information technologies, rare metals, such as indium, are used for the production of flat screens. Not to reuse these metals, nowadays means that the resources will soon be exhausted and none will be available for future generations and for future technologies which will be developed. A Green IT policy could ensure that resources are used efficiently, and that there will be no shortage in the future. It could also reduce the damage to the environment during the production of information technologies [3].

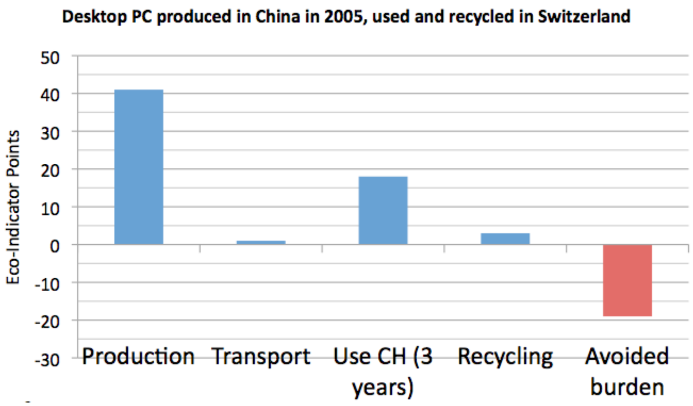

Fig. 1. Comparing production, transport, usage, recycling and loss for a typical Desktop PC, modified from [26]

Interestingly, the usage itself is limited to a few percent of the ecological impact. It must be noted that this study concerns the usage in Switzerland where most of the electricity comes from hydroelectric (50%) and nuclear plants (35%). The International Energy Agency (IEA) [2] publishes regular statistics about the energy production and usage in the world, aggregating them by countries or regions in the world. Thus, depending on the area of production of the electricity, the ecological impact can be drastically different. For example, France is generating electricity altogether about 85% from nuclear plants, and about 10% of this is hydroelectricity, while Austria is 60% hydroelectricity and 10% gas, and China is 85% coal and 10% hydroelectricity. These numbers reflect directly on CO2 emissions. While at the global level the CO2/kWh is averaged at 500g per kWh, in Iceland it is roughly 0, in France about 90g and as much as 1 kg more in China.

Often undervalued is the e-waste, which appears after the usage. The United States' (U.S.) Environmental Protection Agency (EPA) declared that Americans throw out more than two million tons of consumer electronics annually, making electronic waste one of the fastest growing components of the municipal waste stream. In the European Commission (EC) the disposal of e-waste is regulated by guidance such as the Waste Electrical and Electronic Equipment (WEEE) guideline. This guideline has the aim to reduce e-waste and to ensure environmental-friendly cleaning. Unfortunately, this rule is bypassed because of financial reasons. E-waste is transported to the developing world, where the waste is recycled in a very primitive way leading to a contamination of human beings and the environment. Green IT should point out these aspects and should insist that recycling is done in a “green way”.

3.2 Economic and Social Reasons

Besides ecological reasons, there are multiple economic reasons that make Green IT interesting for industry. IT in industry needs energy in the form of electricity and is therefore an expense factor, especially considering the increasing costs of electric energy in the last decades.

Green IT could reduce the consumption of electricity used for IT in companies, thereby decreasing the electricity bills. Actions could take place to assure “green production”, using renewable energy relative to the actual needs of the IT infrastructure.

Companies invest annually a huge amount in information technologies. Mainly high performance technologies are bought, but their memories, storage and computing power and capacity are not well-utilized. Often such investments are too high for the current needs, given that in the course of replacement investments and expansion investments technologies are renewed while it would not be necessary. Green IT could provide a more efficient usage of older equipment and a higher workload of new technologies. Hence, a better utilization of existing resources and the need of new hardware could be reduced. High costs for new acquisitions could be minimized.

Green IT is not only important for industry but is also in the interest of governments. Public administration aims to preserve the environment and to serve the country and its inhabitants. For instance, Germany offers governmental support for companies that reduce environmental contamination. Hence, Green IT can bring governmental funding and tax advantages. Green IT is useful for a government since it aims at conserving the environment while taking a long-term view.

Industry may use Green IT intentions also for marketing aims. Therefore their internal processes or own products may be labeled as green. The company is creating a positive image in a sensitized society [22]. The prime example of this is the “Big Green” project of IBM. IBM promoted the reduction of up to 80% of energy consumption. For several years now, IBM has been promoting energy-efficient solutions and promising that these solutions help to improve the image of clients [23].

First introduced long ago by Jevons in 1865 [17], and re-emerging in the 1990s [18] with the climate change question, the rebound effect cannot be ignored in the context of Green IT. The idea behind it is that the greater the energy reductions that are possible thanks to technological means, the more the global energy consumption will increase due to the resulting increased access to technologies.

4 Final Definition of Green IT

Based on the above definitions and motivations, a definition of Green IT is stated, which is for now the basis for the work described in this paper. *“Green IT is the environmental and resource saving effort in the IT. The reason for using Green IT may arise from economic or ecological interests. Actions can affect on the whole lifecycle* *of information technology – meaning from the construction via utilization through to disposal."*

Green IT should be understood from the tendency to the movement (effort) towards sustainability. In general, as shown in figure 2, sustainability is the area where ecological, economical and social aspects overlap.

Ecological sustainability is oriented closely to the definition that relates to forestry, meaning trees should not be chopped down before others have reached the same height [24]. Ecological and social sustainability represents a visionary world order where the lifestyle of today's society incurs a penalty for future generations, and gives access to this lifestyle to all the society. It is more important to understand the effects of choosing a sustainable course of action than to categorize the action according to its motivation [25]. As already mentioned, there are different motivations for Green IT efforts but the result is more important than the original kind of motivation. It does not matter to the environment why I am saving electricity – to reduce my electricity bill or to have a pure conscience – but the environment benefits regardless.

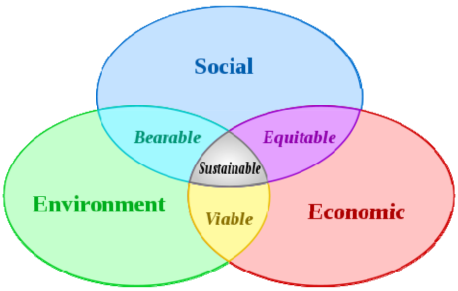

Fig. 2. The place for sustainability (picture from Wikipedia, built from [21])

In the best cases, Green IT is sustainable. In figure 2, Green IT is in the central "sustainable" area and stays there whatever the operations on the system. For instance, buying less expensive hardware will lead to a movement away from sustainability that can be compensated for when this new hardware consumes less electricity. It should be noted that making no effort at all will lead the IT to move away from this sustainability area due to the obsolescence of the equipment.

In the common case, Green IT can be represented in figure 2 as a movement towards the optimal area (i.e., the sustainable area). For instance, calculating the price of the products including the financial costs for the e-waste (for example, people working in this sector need health protection) before renewing some equipment will move within the social point of view towards sustainability.

In the worst case, Green IT is unfortunately a movement away from the sustainable area to a border area, and it is not important towards which field this point is moving. For instance, a company can buy new hardware that consumes more electricity than the older hardware (the business of the company is growing and needs more IT infrastructure), but still consuming the minimum maximum (instead of minimum) electricity from the market for the computing power needed. In that example, the movements in the environment and the economic domains are clearly not towards sustainability. But the company can still advertise some Green IT efforts.

Green IT is always moving, there is always a development in one of the regions shown in the graph. Depending in which direction it is moving, how far it is moving towards the sustainable area or far away from it, you can say that there is still a part of Green IT in these changes. Maybe this new development is only Green IT but it will lead to difficulties in the economic region of the chart. This graph allows us to give a first label to Green IT. All known components will be filled, and the result indicates whether it can still be considered Green IT or not. After developing some standards/limits for Green IT, for the economic, environmental and social aspects, a special innovation, meaning a movement within the Green IT, can be categorized, perhaps even assigning them a value according to their usefulness to Green IT.

5 Analysis of Two Green IT innovation Sources

This section discusses the links between Green IT and innovation. We choose two well-known mature mechanisms for Green IT: server virtualization and hardware cooling. This allows us to describe enough background of the field in order to anticipate in the next section some forthcoming potential innovations.

5.1 Server Virtualization

Server virtualization technologies allow the embedding of services in virtual machines and to group several such virtual machines on physical hosts. This mechanism decreases the number of servers needed to handle users' requests to services. Several studies show that the companies are using server virtualization mainly from an economic point of view: fewer servers mean lower maintenance costs in terms of human resources and hardware changes. This technology serves as a basis for cloud computing, which may not be as green as expected [27], [28]. A recent study from TNS for CSC [10] on 3,645 companies from eight countries shows that companies adopt cloud computing for data everywhere for accessibility and performance reasons as first incentives before economic reasons, while reducing the energy footprint of the company comes after. Green IT is therefore only a side effect of server virtualization.

Interestingly, it must be noted that the server virtualization technology has been developed after the monitoring of standard enterprise services found that only a fraction of the servers were actually used to handle the hosted services. Typically, only 15% to 20% of the servers' resources were consumed to perform useful business over peak load. This over provisioning is actually inefficient but comes with an ignorance of the actual needs of the systems.

Green IT has not been the main reason for the development of innovation in terms of server virtualization. But Green IT benefits obviously from these advances: fewer servers require less electricity to run and less energy (hence materials) to produce, maintain, replace and finally dispose of.

Conversely, Green IT is also a motor for innovation in server virtualization. For instance, to propose innovative Green IT solutions in server virtualization to consolidate the virtual machines in the best configurations (in terms of Quality of Service and energy issues), classical solutions are based on the monitoring of the usage of the servers [11]. Hence the monitoring of the applications on the servers has to be extended to monitor virtual machines. It is not sufficient to know how a server is using its resources; it is also necessary to be precise in the amount each virtual machine is using of the host server in order to optimize the placement of virtual machines on the set of physical hosts. When this monitoring improves, the server virtualization will be more efficient since this precise monitoring will allow for a better consolidation on even fewer servers. Unfortunately this monitoring is not directly possible and mathematical models must be developed. This field is under development and the accuracy of current models are either too low (10% [29]) or too specialized for one benchmark field (3% accuracy, [30]).

This example shows how server consolidation fed Green IT, and vice versa.

5.2 Hardware Cooling

For a long time, computer rooms were small enough in size that their electricity consumption was not an issue. The need to cool the machines made companies deploy air conditioning solutions in the early days. While computer rooms evolved to become data centers hosting thousands of machines to cool, the air was soon seen to be inefficient in terms of heat transfer despite the development of innovative software to arrange and manage computer rooms in the best way. To measure the efficiency of data centers, the IT community developed several metrics like the Power Use Efficiency (PUE) that measures the amount of electricity put into the data center compared to the electricity actually used by the computers. It does not say anything about the actual amount of power needed, and nothing about the impact on the environment (CO2, waste). Indeed, there are several ways to optimize the PUE: to use alternative cooling such as water cooling, free cooling with ambient air, hot/cold aisles in the computer rooms, or better/newer computing equipment While these techniques should actually reduce electricity costs, it is unclear whether this is actually the case, since this may increase the amount of IT infrastructure actually deployed (see the previously mentioned rebound effect). It must be noted that new usage such as social networks, advanced search tools and the like would not exist without innovative solutions to cool data centers for operational reasons.

The side-effect of these developments is a better energy efficiency of individual data centers building up the clouds. But the long-term global impact has not been measured, in particular from an environment-friendly perspective taking also into account Life Cycle Assessment (LCA) and the overall resource usage or CO2 emissions. It then appeared not to be sufficient and new metrics were developed, some of them by large consortia such as the GreenGrid [14], standardization bodies or within research projects like CoolEmAll [15]. For instance the CUE (Carbon Usage

Effectiveness) accounts for the total CO2 Emissions/ caused by the total datacenter energy per kWh, and the WUE (Water Usage Effectiveness) measures the number of liters of water per kWh.To go further Green IT needed to travel in new directions in the field of cloud computing: to take into account the usage of the infrastructure (in terms of business value), the distribution of the tasks in the infrastructure according to heat and production means to favor greener energy, the energy markets, the energy usage, the full life cycle of equipment. For instance, Moore et al. [12] showed the airflow in the rooms, and proposed scheduling algorithms of the tasks in the computer rooms according to the actual heat of the system to avoid hot spots and finally to reduce CO2 emissions.

In [16], the authors exhibit the "Follow the Sun Follow the Wind" (FTSFTW) approach that migrates tasks according to the availability of renewable energy supply to the data centers. While this idea is not new in the industry (service companies with offices spread over the world allow a 24/7 service), its realization is limited to companies with data centers distributed worldwide. However, the advances in cloud computing make this paradigm interesting again nowadays.

These examples show that the need for better and larger IT (optimizing the efficiency of data centers in terms of electricity needs) opened up a number of questions in Green IT (new metrics) and how, conversely, these innovations fed the IT sector with new solutions (such as FTSFTW) improving the overall usage of the infrastructure.

6 Conclusion and Perspective: The Virtuous Circle

The research in Green IT has shown some merits thanks to innovations such as those analyzed in the previous section. Several other options have been developed by industries and researchers that altogether reduced the ecological impact of IT. A virtuous circle can be seen between innovation that drives Green IT, and Green IT that drives innovation. Giving a fine analysis of these bilateral links is necessary to understand how to accelerate the course of industrial transfer.

To analyze this virtuous circle and to propose analytical methodologies to speed up the process is our goal. We aim to pursue this goal in the future, in particular in the light of coming innovations to be accepted by industry players. We believe that the development of Green IT in all its dimensions (including the full life cycle of IT equipment) towards sustainability will enlarge the opportunities for innovation.

A few promising innovations, chosen to be complementary and addressing several aspects of the problem, include:

- Software development toolkits to optimize energy usage of the IT infrastructures. Nowadays software development toolkits do not include any indication of the application's ecological impact on the infrastructure. These toolkits aim at helping developers in writing efficient code in terms of performance (with integrated monitoring/code analyzer), or they aim at hiding the complexity of the runtime infrastructure. Choosing for a developer between two concurrent libraries doing the same work, based on their respective energy impact, is not possible today. Much effort has to be followed to include energy awareness and efficiency at the software level. This can only be achieved with the help of informed development toolkits.

- Developing global knowledge about energy production and markets. Large-scale infrastructure such as that used for cloud computing could benefit from a detailed knowledge of the production means, in real time. Indeed this could help for instance to migrate tasks and divert network traffic to hosts and routes where the ecological impact is minimum. We believe that SmartGrids have to be tightly coupled with IT infrastructure to provide the necessary information on a large scale.
- Usage, production and optimization of (renewable) energy means direct links with the IT infrastructure. Nowadays too much energy is wasted by inefficient transport and transformation of electricity between their production points and their utilization places. We foresee the developments of renewable energy such that its source can be located closer to its usage, limiting the transport costs and allowing for the direct provisioning of current to computer rooms, with on-site innovative batteries.
- Changing the production of IT hardware by exploring some alternatives for replacing rare metals which have to be used with care, both from an ecological point of view and also from a political point of view. This research on rare metals might be post-disruptive since all the production flows have to be rethought.

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