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Green Computing

# Green Software

*Giovanna Sissa*



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*An effective insight about ICT environmental sustainability requires to pay attention also to the software features, being this another responsible for the CO2 emissions. The energy consumption in the computer's use phase doesn't depend only from hardware but also from software configuration and from its efficiency. Software is also responsible for the Induced hardware obsolescence. The actual computer lifecycle is shorter than the potential one. Some real data and interview will give evidence on how software improvements, aimed at making the information system configuration more effective, will lead to energy consumption reduction. A software-based approach will also allow a longer use for PCs, respecting the environment, saving energy, emissions and money, and, in the meantime, moving toward the cloud computing paradigm. This paper includes an interview with Gianluigi Castelli, Executive Vice President Information & Communication Technology of the Italian company ENI.*

**Keywords:** Environmental Sustainability, eWaste, Green Computing, Green Software, IT Management Software, Thin Client.

## 1 The Environmental Impact of the ICT Sector

Information and communication technologies (ICTs) have been contributing to environmental problems: computers, electronic devices and ICT infrastructure consume significant amounts of electricity, placing a heavy burden on our electric grids and contributing to greenhouse gas emissions (see Figure 1). In 2007, the total footprint of the ICT sector – including personal computers (PCs) and peripherals, telecom networks and devices and data centers – was 830 MtCO2 emissions, about 2% of the estimated total emissions from human activity released that year (a figure equivalent to aviation industry) [1].

Additionally, ICT hardware poses severe environmental problems both during its production and its disposal. Each stage of a computer's life cycle, from its production, throughout its use, and into its disposal, presents environmental problems. Manufacturing computers and their various electronic and non-electronic components consumes electricity, raw materials, chemicals, and water, and generates hazardous waste [2,3]. Use phase is also energy intensive.

All these, directly or indirectly, increase carbon dioxide emissions and impact the environment. The trend is to increase in the BAU (Business As Usual) scenario [1] (Figure 1).

The total electrical energy consumption by servers, computers, monitors, data communications equipment, and cooling systems for data centers is steadily increasing.

The effects of ICT on the environ-

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ment are commonly ranked in first, second and third order effects [3,4].

The first order effects are directly related to the mere physical existence of ICT and include production, use and end-of-life treatment. The second order effects are related to the application of ICT and include effects leading to optimization of processes in other sectors (e.g. traffic optimization), substitution effects (e.g. e-processes that replace traffic) and induction effects (when ICT creates more demand in other sectors). The third order effects are related to the societal changes that ICT brings along and they are more difficult to foresee and quantify. This includes the deep structural change towards a de-materialized economy, the rebound effects, and the increased dependency on the critical infrastructure of ICT.

### 1.1 A Rebound Effect

Each PC in use generates about a ton of carbon dioxide every year [5]. ICT equipment accounts for about 10% of the UK's total electricity consumption (worth the equivalent of four nuclear power stations). Between 2000 and 2006, energy consumption from non-domestic ICT equipment increased by more than 70% and it is expected to grow by a further 40% by 2020 [6].

The energy consumption resulting from the use of computers, the internet and other forms of ICTs has risen enormously over recent years [9]. ICTs are continuously making astounding progress in technical efficiency. The time, space, material and energy needed to provide a unit of ICT service have decreased by three orders of magnitude (a factor of 1000) since the first PC was sold [4].

ICT devices are becoming increasingly more compact and energy efficient.

Computers are continuously making astonishing progress in energy efficiency, measured in performance per watt[1], due to innovative design techniques, coming from technological aspects to the processing architectural dynamic management. The power density[2] is also increasing [8].

The well-known principle called Moore's Law, according to which the number of transistors per microchip doubles every 18-24 months, has yet to be disproved. But Moore‘s Law in physical terms and Moore‘s Law in economic terms are different. For an exponential growth of performance, we have a double exponential growth per chip of performance per money. The miniaturization paradox indicates that hardware is getting cheaper faster than it is getting smaller [3, 9].

By the same token, though, computers are getting cheaper – and so their use is therefore becoming more widespread. The same is true for using internet and telecommunication services. More and more powerful devices are used by more and more people. The number of devices and uses is currently rising faster than corresponding developments in energy and materials efficiency. Research on energy and sustainability refers to this phenomenon as a "rebound effect" [3]. Rebound effects occur if, and when, the efficiency of providing a service is increased but there is no factor limiting the demand for this service, such as the price to be paid or the time needed for consuming it. The economic system (as a functional system of society) adapts to the higher efficiency level at which the service is provided increasing the demand for the service [4].

The demand for ICT is increasing even faster than the energy efficiency of ICT devices; the total energy demand of the installed hardware base is growing [5,10].

As manufacturers competed to create ever-faster processors, smaller and smaller transistors (running hotter and consuming more electricity) were used to form the basis of each new generation. Increased operating temperature added to the consumption of power, requiring more and more cooling fans. Modern IT systems provide more computing power per unit of energy (kWh) and thus reduce energy consumption per unit of computing power. Despite this, they are actually responsible for an overall increase in energy consumption and for an increase in the cost of energy as a proportion of IT costs. This is because users are not simply using the same amount of computing power as before, while using the new technology to reduce their power consumption (or operating temperatures), nor are they using technology to leverage savings in energy costs or in CO2 production. Instead, users are taking and using the increased computing power offered by modern systems regardless implication on sustainability. New software in particular is devouring more and more power every year. Some software requires almost constant access to the hard drive, draining power much more rapidly than previous packages did.

The advent of faster, smaller chips has also allowed manufacturers to produce smaller, stackable and rackable servers allowing greater computing power to be brought to bear but with no reduction in overall energy consumption, and often with a much greater requirement for cooling [11].

## 2 Green ICT and Green Software

Green ICT, or Green Computing, is 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 [7]. Green ICT includes the dimensions of environmental sustainability, the economics of energy efficiency, and the total cost of ownership, which includes the cost of disposal and recycling. Green ICT benefits the environment by improving energy efficiency, lowering

[1] Performance per watt is a measure of the energy efficiency of a particular computer architecture. Literally it measures the rate of computation that can be delivered by a computer for every watt of power consumed. The performance and power metrics used depend on the definition; reasonable measures of performances are FLOPS, MIPS, or the score for any performance benchmark

[2] Power density can be measured in W/m2 or W/ft2 (Watts per square meter of foot).

 

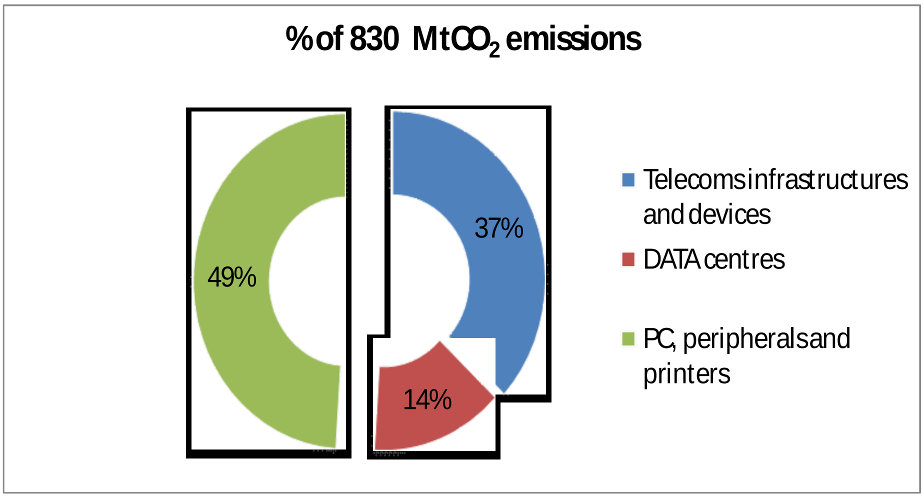


**Figure 1:** ICT Footprint by Sector 2007 (Gesi Group, Smart 2020).

greenhouse gas emissions, using less harmful materials, and encouraging reuse and recycling [5].

Green design, green manufacturing, green use, green disposal are complementary paths of green ICT. Only focusing on these four fronts we can achieve total environmental sustainability from the IT side and make IT greener throughout its entire lifecycle.

Green design and manufacturing are not the matter of this paper. The focus will be on the green use and also on green disposal, and on the role played by the software in a green strategy.

Corporate and their IT department are recognizing their impact on "carbon footprint" on the environment and are actively engaged in finding green IT solutions. While many have looked to hardware and power systems as part of these solutions, it is becoming increasingly recognized that software management is also a key part in the role of the ICT sector [12].

It is possible to tune a piece of software to do the job it was doing before, but on less power and less CO2 generation (not exactly the same), or even write software from scratch to be 'greener' and more energy-efficient. This goal is easier to achieve on hardware that is energy-efficient already such as smart handhelds, laptops and newer desktops/servers designed and built after it became fashionable to compete on computing power per watt[3]. The micro-processors within electronic equipment require energy both to operate and for cooling fans. Improvements in chip design (such as 'multi-core' processors) can save 30-60% of the energy used by the processor if software is written to take advantage of this capacity [10].

Low power software, used since time in the design of embedded systems, deals with design oriented toward energy saving, starting from low level compiling and programming aspects (like, in example, data architecture) up to operating systems. The growth of ICT leads to a larger attention in energy saving in all sectors.

The continued rise of Internet and Web applications is driving the rapid growth of data centers. Enterprises are installing more servers or expanding their capacity. The number of server computers in data centers has increased six fold up to 30 million in the last decade, and each server draws far more electricity than earlier models [5,11,6], because is more powerful. A key green objective in using computer systems and operating data centers is to reduce their energy consumption, thereby minimizing the greenhouse gas emissions [5].

But green ICT is not only a matter of hardware. Software plays a critical role on each phase of the life cycle. In the use phase, as we will see later, in an interview where will be given data and evidence about the energy saving coming from better software efficiency. And software can play a green role also at the end of the hardware lifespan.

Green computing can be aided by software solutions as well. There are lots of software-based solutions that not only monitor and better utilize existing resources, but can also go beyond and nullify the need to add extra hardware as the company expands, meeting the green requirement with current infrastructure.

I will use the term "green software" in a broader sense than the usual meaning of it. I define as "green" every software taking into account some environmental aspects and allowing ICT to be greener. Let's see how, starting from the Data Center, software is put into relation with energy consumption.

### 2.1 Greening Data Centers

It is estimated that a medium-sized server has roughly the same annual carbon footprint as a SUV vehicle running 15 miles per gallon. The power required for a rack of high density server blades can be 10-15 times greater than a traditional server [6].

To understand how to reduce energy consumption in a data center, we need to know where and how energy is used. Each component is divided into two portions: IT equipment (servers, storage, and network) uses about 45% of the energy, and the infrastructure

[3] <http://www.earth.org.uk/low-power-software.html>.

that supports this equipment - such as chillers, humidifiers, computer room air conditioners, power distribution units (PDU), uninterruptable power supplies (UPS), lights, and power distribution -uses the other 55% of the energy[13].

Thus, IT equipment does not use 55% of the energy that is brought into the data center, so this portion of the energy is not producing calculations, data storage, and so forth. Energy savings and efficiencies for non-IT equipment can reduce this inefficiency [13].

As far as the energy consumption of the IT equipment level, in a typical server, the processor uses only 30% of the energy and the remaining of the system uses 70%.

Commonly, servers are underutilized, yet they consume almost the same amount of energy as though they were running at 100%. A typical server utilization rate is 20%. Underutilized systems can be a big issue because a lot of energy is expended on non-business purposes, thus wasting a major investment [13].

For each watt used for computational resources, the processor uses 5 watts, the server 16 watts and the data center 27 watts, i.e. we need to spend 27 watts of power for each watt spent for resource usage.

Data center efficiency can be improved by using new energy-efficient equipment, improving airflow management to reduce cooling requirements, adopting environmentally friendly designs for data centers, investing in energy management software.

The measure of direct electricity consumption to power servers compared to the indirect electricity used to cool the equipment is known as the Power Usage Effectiveness (PUE). As PUE increases, the indirect cooling electricity consumption, compared to the direct electricity used by the server increases. A PUE value of less than two is considered to be good practice [6,14, 15]. The European Commission launched a "voluntary code of conduct for data centres" in November 2008, which aims to raise awareness of their energy use. It recommends best practice and targets for data centre owners, whilst avoiding prescription of specific technologies [14,10].

Software solutions are very important to energy efficiency: virtualisation, efficiency, data center consolidation, power server management are important areas for energy efficiency [12].

### 2.2 Virtualisation

The biggest technology that has enabled software-centric green ICT approach is virtualization. The idea is pretty simple: a host software (a control program), creates a simulated computer environment (a virtual machine) for its guest software. The guest software, which is often itself a complete operating system, runs just as if it were installed on a stand-alone hardware platform.

With virtualization, one physical server hosts multiple virtual servers. Virtualization enables data centers to consolidate their physical server infrastructure by hosting multiple virtual servers on a smaller number of more powerful servers, using less electricity and simplifying the data center. Besides getting better hardware usage, virtualization reduces data center floor space, makes better use of computing power, and reduces the data center's energy demands [5].

Virtualisation technology allows fewer servers to store the same amount of data. Server virtualisation involves a software application dividing one physical server into multiple isolated virtual environments [6].

Virtualisation and server consolidation can allow users to 'do more with less', allowing one large server to replace several smaller machines. This can reduce the power required and the overall heat produced. By reducing the number of servers in use, users can simplify their IT infrastructure, and reduce the power and cooling requirements [11].

### 2.3 Software and Energy Efficiency

Despite the trend towards server virtualisation and consolidation in some companies, business demand for IT services is increasing, and many companies are still expanding their data centers, while the number of servers in such data centers is still increasing annually by about 18% [11].

Several measures can be taken in order to increase energy efficiency in data centers.

The cause-effect chain starts with applications and continues through the IT hardware and the power supply, right up to building planning and cooling as well as energy management. The key idea is that measures are most effective at the start of this chain. It can look trivial to say, but when an application is no longer needed and the accompanying server is therefore switched off, less power is used, the losses in the UPS (Uninterruptible Power Supply) system decline, and the cooling load is reduced [7].

The starting points for an energy efficient data center are the applications and the data [7]. It often happens that, although a third of all applications is no longer needed, they nevertheless continue to operate on the server. And the difference in the extent to which certain largely identical applications use hardware resources is often not insignificant. For the management of the energy efficient data center, this means that the applications and the data must be examined regularly, and that applications and data which are no longer needed should be deleted as far as possible.

### 2.4 De-duplication of Data

We live in an era of unprecedented information growth. The Moore Law and the idea that storages resource costs are decreasing endlessly, have as negative side effect that data managers don't pay sufficient attention to the redundancy of data.

In 2006, 161 exabytes ($161x10^{12}$ bytes) of digital information was created and copied. That is equivalent to three million times the information in all the books ever written, or 12 stacks of books, each extending from the Earth to the sun [16] It is estimated that the amount of information created and copied in 2011 will increase six-fold from 2006 [16].

Data de-duplication essentially refers to the elimination of redundant data. In the deduplication process, duplicate data is deleted, leaving only one copy of the data to be stored. However, indexing of

 

<table>
<tr><td colspan="3">Payroll values per employee (about 35.000)</td></tr>
<tr><td></td><td>Before Optim.</td><td>After Optim.</td></tr>
<tr><td>Access to a view (time)</td><td>3.5 sec</td><td>0,01 sec</td></tr>
<tr><td>Access to a view (#buffer)</td><td>≈223.000</td><td>163</td></tr>
<tr><td colspan="3">Power ratio <1/350</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td colspan="3">Customer data enrichment (1.800.000 customers)</td></tr>
<tr><td></td><td>Before Optim.</td><td>After Optim.</td></tr>
<tr><td>Elapsed time</td><td>200h</td><td>55 min</td></tr>
<tr><td colspan="3">Power ratio < 1/218</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td colspan="3">Customer data search</td></tr>
<tr><td></td><td>Before Optim.</td><td>After Optim.</td></tr>
<tr><td>Search</td><td>6,62 sec</td><td>0,01 sec</td></tr>
<tr><td>Search by code</td><td>14,49 sec</td><td>0,01 sec</td></tr>
<tr><td>Search by company name</td><td>18,26 sec</td><td>0,05 sec</td></tr>
<tr><td>Search by user name</td><td>2,38 sec</td><td>0,01 sec</td></tr>
<tr><td colspan="3">1/1449 < Power ratio < 1/238</td></tr>
</table>

**Table 1:** Figures about Energy Reduction through Software Intervention (Preproduction Phase). (Source ENI).

all data is still retained should that data ever be required. Deduplication is able to reduce the required storage capacity since only the unique data is stored. Data deduplication lets users reduce the amount of disk they need for backup by 90 percent or more. With reduced acquisition costs—and reduced power, space, and cooling requirements - disk becomes suitable for first stage backup and restore and for retention that can easily extend to months. With data on disk, restore service levels are higher, media handling errors are reduced, and more recovery points are available on fast recovery media. Data deduplication also reduces the data that must be sent across a WAN for remote backups, replication, and disaster recovery.

## 3 IT Management Software

Hardware manufacturers continue to drive towards greater efficiency for power consumption and total heat output (which lowers cooling costs), and increased capacity within their server, network and device technologies [17].

According to the EPA study [18] *"…existing technologies and design strategies have been shown to reduce the energy use of a typical server by 25 percent or more. Even with existing IT equipment, implementing best energy-management practices in existing data centers and consolidating applications from many servers to one server could reduce current data center energy usage by around 20 percent."* Streamlining IT performance does not have to mean increasing energy consumption.

Cost savings and the reduced environmental impacts for excessive power consumption are necessary. Well-executed strategies in line with the proper IT management software solutions allow these companies to swiftly execute and accurately identify its benefits. Going green in ICT does not necessarily require a substantial investment in new technology. Enterprise IT management software can leverage on legacy and new technology investments to achieve greater efficiencies faster and at lower costs, while accurately measuring IT savings and impact on the environment [17].

Today's trends in ICT management show undeniable proof of the benefits from server consolidation and optimization through the use of virtualized and automated environments, which include greater efficiency in overall server utilization.

To optimize ICT assets through virtualization and consolidation, organizations must gain a thorough understanding of the current state of utilization and associated dependencies. This, in short, involves leveraging IT management tools to gather and report asset catalogs (through asset discovery) on both software and its supporting hardware infrastructure. Additionally, application dependencies must be accurately and dynamically mapped so that the impact of consolidation is both recognized and anticipated.

Power management software can reduce energy consumed by idle equipment [5]. The National Energy Foundation [19] estimated that the implementation of power management software has the capacity to reduce CO2 emissions in the UK public sector by 140,000 tonnes per year. Power management software remotely ensures that equipment is put into sleep mode and then woken up when required.

IT management software can play an even greater role in increasing IT efficiency and moreover measure progress against stated goals. However, IT management software can also make better use of existing equipment and reduce the need for purchasing new hardware [17].

But the role of software is not only related to IT management.

### 3.1 Saving Energy through Software Improvement

In the interview with Gianluigi Castelli, Executive Vice President – Direction Information & Communication Technology of the Italian company ENI, some examples of energy efficiency improvement driven by the software are given (see interview below).

Software improvement on data architecture or database feature leads to dramatic reduction in energy consumption, pinpointing the importance to operate at the base of the cause-effect chain.

CO2 emissions relay also on a big amount of elementary operations, like database enquiries. Improving the efficiency of elementary operations that are made on a huge amount of data can lead to significant energy saving.

If the access of a single view of the pay slip in a big organization is improved from 3,5 sec to 0,01 sec, the power usage is reduced of 300 times, as stated by Castelli. The figures are impressive (see Table 1).

The main improving areas are in the pre-production phase, mainly those related to data architecture or to the use of feature of big company database.

Software is becoming the true efficiency factor. The relationship between software and hardware is the same that occurs between painter and brush: The painter is the driver of the picture, not the brush. We can have a good brush, but without a good painter is useless. The software is at the basis of the chain; each gain in efficiency at the base of the chain can lead to "order of magnitude performance improvements".

## 4 Reducing Energy Consumption of PCs (Office ICT Equipment)

We can significantly reduce energy consumption by making small changes to the way we use computers. While the savings in energy costs per PC may not seem like much, the combined savings for hundreds of computers in an enterprise is considerable. We can reduce PC energy consumption by adopting several measures, like enabling power management features. Without sacrificing performance, we can program computers to automatically power down to an energy-saving state when we aren't using them.

Over 40% of the UK adult population regularly use a PC at work, and as many as one-sixth (18%) of these computers are never switched off at night or weekends, with a further seventh (13%) not switched off on some days each week. The resulting energy wastage is estimated to amount to 1.5 billion kWh(1.5TWh) of electricity/year. Translated into emissions, this equates to 700,000 tons of CO2 being produced as a result of workers not bothering to shut down their PCs [19,11].

By turning off just one computer overnight we can save 235kg of CO2 in a year. Over the whole estate the potential is enormous – turning off every one of Whitehall's 500,000 computers at night would have the same effect as taking 40,000 cars off the road [20].

The US Environmental Protection Agency (EPA) estimated that providing computers with a sleep mode reduces their energy use by 60–70 percent [18,21].

We have to take into consideration the users approach to computing (both for simple user and for power users). The PC-era, based on local applications, is going out. The cloud-computing-era is based on devices always-on and on the browser, seen as the main user interface for services, applications or data on the Internet. In this approach the thin client assume a strong value and can be seen as an environmental opportunity for green cloud computing. Let me say why and how.

### 4.1 Thin-client Computers

In client/server applications, a thin client is designed to be especially small so that the bulk of the data processing occurs on the server. Unlike a typical PC - that has the memory, storage and computing power on its own - a thin client usually refers to software: a virtual desktop that is designed to serve as the client for client/server architectures.

With thin clients, the desktop environment is run on the server, and then remotely displayed on the thin client. You need to manage this on the server with a ***V**irtual **D**esktop **I**nfrastructure* (VDI) , software that creates the desktop images, stores them on servers and sends them over the network to the thin clients.

A thin client does not contain a hard drive, DVD or CD-ROM, a fan or other moving parts, so it is typically smaller and cheaper than traditional PC or notebooks. The thin client is light, essential, platform independent and without maintenance requirements. Computation and resources needed for will be centralized and easy to maintain and to manage.

While the server must be robust enough to handle several client sessions at once, the clients can be made out of much cheaper hardware than a fat client. This reduces the power consumption of those clients, and makes the system marginally scalable. The thin clients themselves in general have a very low total cost of ownership, but some of that is offset by requiring a robust server infrastructure with backups and so forth. This is also reflected in terms of power consumption: the thin clients are generally very low-power, but the servers are higher-power and require an air-conditioned server room.

The German Fraunhofer Institute [22] estimated that a thin client configuration is twice as energy efficient as using desktop PCs [4], though these findings have been disputed as under-

 

**INTERVIEW**
**with**
**GIANLUIGI CASTELLI**

Executive Vice President Information & Communication Technology, ENI

***In a conference you talked about the energy savings Eni has achieved because of software improvements. How did you choose the applications to improve?***

We have been focusing on the applications under development or close to the "go live", as it is obviously simpler and cheaper to act during the development or during the performance tuning than trying to modify existing and mature applications. As we have recently introduced a phase of performance tuning in our software development process for all the new applications, we have been able to collect very enlightening data during pre-production. It's during this phase that we have identified the areas of improvement, mainly due to poor data architectures or bad use of DBMS features. The achievements resulting from our [effort] been surprising: in quite a few cases the performance improvement has been of 3 or even 4 orders of magnitude. Clearly this suggests that larger investments are required, both by large IT user companies and their suppliers, to improve the skills of the technical community to move it drastically from a quite generic set of IT practitioners, into a much better-than-today skilled set of IT professionals.

Paying much more attention to the intrinsic inefficiency of certain programming languages (e.g. those based on virtual machines or heavily based on interpretation rather than compilation) and development environments would deliver extra benefits. But this would mean to get out of the off-the-shelf solutions mainstream….

***Have you been able to quantify the energy savings resulting from the software changes?***

It's not easy to establish a rigorous measuring system as a lot depends heavily on the usage profile, which, on the other hand, depends on habits, human mistakes, cycles or recycles driven by company's processes. It's also difficult, without a very fine grain monitoring capability, to determine a sort of "specific consumption" for software. Furthermore, as the hardware sizing is done starting from the performance of existing software, the hardware is often oversized, but the exceeding computing power cannot be made readily available, at least until an internal cloud computing model is fully implemented.

However I have no doubts that software is becoming the true efficiency factor, thus key to the overall energy savings efforts. Software stays to hardware as the painter stays to the brush. But right now it is easier, and sometimes cheaper, buying new brushes rather than better painters.

Ttimes are changing: cloud computing solutions implemented by Google are a clear example of how software is becoming the true efficiency factor. I strongly believe that this new awareness will grow over the years, and that software efficiency will become more and more relevant though computing power is abundant.

Nonetheless we have to be aware that the old habit of adding computing power to mitigate software poor performance has created a culture that is now hard to eradicate.

***These changes have been expensive to implement?***

Actually not, because of what I said before, that is when they have been introduced in the software lifecycle. But I'm strongly convinced that it is necessary to invest a lot to improve the IT culture and the technical competence that has being weakening in the past ten years or so. Let me make an example to support this: recently an IT professor (who's a good friend of mine) has made a test in quite a few important universities, to check how good is the compe-

. /..

estimating the cost of the increased power usage of servers needed to support the clients [10].

The thin client decouples the user interface from the computational resources. The thin client concept means that an end device uses data supplied completely from a server. It has no medium for data storage and the operating system is started either by flash-card or via the network, where the user programs are stored. Thin Clients are offered either in pocket-book size or are completely integrated in TFT displays [23].

The thin client incorporates very few electronic components, gets by on just 20 Watts including server share and – needing no fan – is totally noiseless. Modern thin client devices can be operational just 30 seconds after being switched on.

In addition to their advantages with regard to space, energy and noise level, thin-client solutions are light, essential, platform independent and require no maintenance.

Those are advantages of particular interest to schools: the user software has to be installed only once – on the server. So if members of the teaching staff want to implement a new programme, it simply has to be installed on the server and the new application is available to all the connected work stations. The same, of course, is true for updates, which also have to be installed only at one point. Furthermore, thin clients incorporate their own dedicated operating system. This dispenses with the need for software maintenance and the device cannot crash or get hung up.

Thin client is the best answer for companies, organizations, universities or schools that have a large number of PCs running on the network and are looking at reducing the energy consumption. It also makes the desktop PCs more reusable reducing the property need of companies.

Thin client is first of all a software concept [2]. Thin clients can be specific devices, as said, with a very high level of energy efficiency, but can also be implemented using normal desktops. In both cases their use leads to environmental advantages. The

Borderstep Institute for Innovation and Sustainability has foreseen for the 2012 German schools two different scenario. The business as usual scenario for 2012, foresees that in the coming years most schools will continue to be equipped mainly with desktop PCs having only slightly less electricity consumption and supplemented with about 15 per cent notebooks. The procurement of additional computer stations would result in a total electricity consumption of 178 GWh for their operation.

In an energy efficient scenario the new PCs needed would be more efficient (consuming an average of only 60 watts by 2012), and, as a parallel development, the share of notebooks would rise to 22 per cent, thin clients to 12 per cent, and compact computers to 7 per cent, then electricity consumption could be reduced to 112 GWh. And this in spite of an increase in the number of computer work stations from the current 1.4 million to approx 2.3 million devices [24].

The notion of a thin client extends directly to any client–server architecture: in this case, a thin client application is simply one which relies on its server for processing. It i s possible to implement thin client with obsolete PCs via software, using for example open source software.

The terminal server can be implemented using obsolete hardware too and free open source solution, like, for example, LTSP (Linux Terminal Server Project) [2,25]. Before seeing how and when there is an environmental benefit coming from the reuse of old PC as thin client, let's see which, if any, is the relationship between software and hardware obsolescence.

tence in writing efficient software. The result has been quite discouraging: even in case of correct solutions of a set of combinatorial problems, the approach has been such that either the computation time was unacceptable (an estimated time of more than 1 year elapsed) or the memory usage was excessive, with a 12.5Gbytes occupancy, whilst a well written solution executes in less than 1 second, requiring less than 1Kbyte of memory. In another case, software written by a system integrator required about 24 hours of CPU time and a few Gbytes, after optimization it runs in 2 seconds and less than 1 Mbyte.

So let me insist on the need to develop and reinforce the technical skills overall, going back to the basic of algorithms and programming techniques to rebuild the solid foundations we need.

What software domains are expected to deliver most benefits to reduce energy consumption and, more generally, the impact on the environment?

There isn't a single recipe. In the application software of a large company I would focus on the architecture and the toolset: multiplexing, multithreading, more efficient languages (Java isn't an efficiency champion….), horizontal DBMS. But, we would need a much larger number of painters. In the medium-to long-term, cloud computing could really deliver a lot of efficiency without affecting the internals of existing applications.

***Do you think that the development energy efficient data center will continue once we will get out of the economic crisis?***

I think that what's happened and it's happening regarding the Data Centers can't be catalogued as "reduction of consumption". It has to do with a true waste of resources. Data Centers ancillary consumptions have reduced by a factor of ten in a few years. Next steps will target the usage of energy inside computers (efficiency of transformers, integrated cooling systems, forced ventilation, and so on) whilst for the Data Centers the challenge is to move from energy saving to energy retrieval, in particular retrieving and reusing the heat dissipated by the computers themselves. The target is to achieve P.U.E. less than 1.

Do you think we are already forming the new IT professionals who could cope with and manage these challenges? What's needed? It's just a tuning of the existing skill or do we need something more radical?

Data Center designers have always thought that stupid computers were placed into complexly engineered buildings. Obviously this is not true. A data center has an energy density in the range of a few KW/cu. meter maximum. CPUs have an energy density in the range of GW/cu. meter. A Data Center has some tens of components, whilst typical software is made by millions of instructions. Complexity lies in software and software people will become progressively the managers and owners of the integrated infrastructure made by several components: software, hardware and the Data Centers themselves. Therefore some new skills will be developed to overcome the current competency silos.

### 4.2 eWaste and SIHO (Software-Induced Hardware Obsolescence)

The ICT sector is coming more and more under the spotlight, since, at a rapid increasing pace, it is entering almost all aspects of our lives.

As ICT is more and more widespread the lifespan of devices becomes shorter.

Computer components contain toxic materials. Increasingly, consumers discard a large number of e-waste: old computers, monitors, and other electronic equipment two to three years after their purchase. Most of this ends up in landfills, polluting the earth and contaminating water. The increasing number of computers and their use, along with their frequent replacements, makes the environmental impact of ICT a major concern.

Not only the eco-toxicological effects of the substances used in, and emissions from, the production process, but also the material intensity of the raw materials that are used – mainly non-renewable and thus finite – show that ecological footprint is becoming increasingly larger due to the growing intensity in the use of ICT. When ICT components are running, they consume a considerable amount of energy. But the fast growing amount of e-waste from ICT usage – caused by the shorter innovation cycles and the associated shortened usage time of electronic devices – is causing a problem. In Europe the quantity of old electrical equipment is growing at a rate almost three times faster than other types of waste. Often old equipment is reused in less developed countries with lower environmental standards under conditions that put people's health and the environment at risk [26].

Then, as said, the total environmental sustainability must be achieved throughout the entire lifecycle of ICT products. But we have always to remember that we are speaking mainly about computers and computers are not only hardware but also software. What about the "Computer lifecycle"? And what about software role?

Software life cycle is not governed by the same physical breakages and parts replacement that contribute to hardware TCO (Total Cost of Ownership) [26]. Rather, the life cycle of software is dependent on a number of interrelated factors, most notably the availability of a product, availability of support, functionality and hardware specifications. With proprietary software, the life cycle can be defined as the period during which the manufacturer sells and supports its wares. Usually proprietary products are removed from the sales channel some time before official support is discontinued.

If the software helps the hardware to come closer to the ideal of load-proportional power demand, it has an optimization effect on the use phase. If a new software version demands for more hardware capacity, it increases the demand for PC hardware by shortening the use phase. The latter effect has been called Software-Induced Hardware Obsolescence or SIHO [27]. This is another rebound effect [3,4,2].

In particular computers are getting obsolete very quickly because new operating systems require faster processor, larger memory and powerful hardware. From an environmental standpoint re-use of products must be considered far preferable to all form of waste management. Extending the life cycle reduces the amount of e-waste with an important positive feedback on the environment [2, 27].

The life of ICT assets can be extended by reusing them within the organization and/or externally. Energy efficiency initiatives in ICT have mostly focused on consumption while in use. However, a large part of the environmental impact of a device comes during its manufacture and disposal. The whole life impact of equipment is much more difficult to measure than the in-use energy consumption, because it is spread through a long supply chain. This uncertainty makes it difficult to know when it is better to extend the life of equipment, thus reducing the sector's total emissions from manufacture to disposal; or when replace old equipment with new equipment that is more efficient in use [10]. Although not a focus of this paper, the whole life environmental impact of ICT concerns not just the $CO_2$ emissions but should also consider the extraction and disposal of harmful materials.

How to extend the life of obsolete computer not according to the classical second hand idea, but rethinking the reuse on the basis of cloud computing paradigm, again, it's only a matter of software, knowledge and skills. High professional solutions, based on open source software, can be suitable for a socially sustainable re-deployment.

### 4.3 The Green Data Cloud

According to the Wikipedia the term "cloud", or "cloud computing", used as a metaphor for the Internet, "*is based on an infrastructure and business model whereby – rather than being stored on your own device – data, application, and other services are delivered to your device, in real time, from the Internet*". The cloud has been a boon both for the companies hosting it and to consumers who now need nothing but a personal computer and Internet access to fulfill most of their computing needs.

Google is perhaps the most famous cloud based company to demonstrate the potential of a cloud paradigm to drive a hugely successful business model. All of Google's signature products - Gmail, Google Documents or Google Earth – are delivered from the cloud.

The use of virtualization in clouds has created a new set of layers: applications, services, and infrastructure. These layers don't just encapsulate on-demand resources, they also define a new application development model. And within each layer of abstraction there are myriad opportunities for defining services that can be offered [28].

Software as a Service (SaaS) is at the highest layer and features a complete application offered as a service, on demand, via multitenancy- meaning a single instance of the software runs on the provider's infrastructure and serves multiple client organizations. Example are Salesforce.com, or the Google Apps, offering basic business services such as e-mail.

The middle layer, or Platform as a Service (PaaS) is the encapsulation of a development environment abstraction and the packaging of a payload of services. PaaS offerings can provide for every phase of software development and testing. Examples include Google App Engine, which serves applications on Google's infrastructure.

Infrastructure as a Service (IaaS) is at the lowest layer and is a means of delivering basic storage and compute capabilities as standardized services over the network. Servers, storage systems, switches, routers, and other systems are pooled (through virtualization technology, for example) to handle specific types of workloads — from batch processing to server/storage augmentation during peak loads. The best-known example is Amazon Web Services.

To move to cloud computing appears to be more environmentally friendly compared to traditional data center operational / deployment models. The rule of thumb says that reducing the number of hardware components and replacing them with remote cloud computing systems reduces energy costs for running hardware and cooling, as well as reduces carbon foot print while higher consolidation/optimization will conserve energy.

The cloud's efficiency and increased utilization would achieve energy savings.

Cloud computing it's a world where the network is the platform for all computing, where everything we think as a computer today is just a device that connects to the internet.

Cloud computing is a style of computing in which IT-related capabilities are provided as a service, allowing users to access technology-enabled services from the Internet without knowledge of, expertise with, or control over the technology infrastructure that supports them. The common theme is reliance on the Internet for satisfying the computing needs of the users.

Like virtualization had some years back, cloud computing too has hidden green. By the use of SaaS, many companies have been able to do away with the need for physical infrastructure and thus reduce their energy footprint. Likewise, through the use of thin clients, companies are also able to reduce the need for desktops on the front end. Thus, in many ways cloud computing "enables green", and could be a great way to reduce the carbon footprint.

The replacement of traditional desktop PCs with a thin client and the hosting of a virtual desktop on a remote server can be a suitable green solution [29].

Old PCs can easily be converted into thin clients, further reducing equipment costs - the costs of operating system licenses and upgrades are reduced or even eliminated [2, 25]. The novelty in this approach is represented by the opportunity that cloud computing can give to the final users, giving them the possibility to be free from one specific access device, like traditionally their own PC, and shifting their working environment on virtualized desktop.

An example of thin client implementation using obsolete hardware and the virtual desktop was made in the Italian schools [25]. Otherwise than in the cited German approach [21], where thin clients are specific new generation devices allowing the best energy saving [26,18], the implementation of thin client on obsolete computer allows to "increase" till a 100% the lifespan of a PC, decreasing then the e-waste [2,25].

Software skill are required to match the features of obsolete but still working equipment with free open software solution able to satisfy the final user and to work well on the available hardware.

Cloud computing contributes to reduce CO2 emissions in several ways. It, again, leads to the key idea, i.e. that is the software to drive toward green the whole ICT system.

We have to take into consideration that remote resource use reduces but doesn't eliminate CO2 emissions, for the related Internet access. The average Google query produces roughly 0.2g of CO2. Not only is energy use very small, but web searches often take place of more carbon and time intensive activities, such as driving a car to a library or spending hours navigating shopping malls. To put these numbers in perspective here are the CO2 emissions of some everyday activities compared with "Google search". In the time it takes to do a Google search, your own personal computer will likely use more energy than Google uses to answer your query, if you take as a baseline the assumption that a laptop in use produces 20g of CO2 in one hour[4]. In comparison using a PC & monitor for one hour produces 75g, one physical copy weekday newspaper 173g and travel from Paris to Geneva by TGV 13 kg, by plane 56 kg (Economy Class) [30].

## 5 Conclusions

Reducing the environmental impact of ICTs requires environmental skills as well as ICT-related skills. Furthermore, using ICT applications needs awareness about the environmental implications of personal behavior. A green ICT strategy have to start from increasing public knowledge about ICT and its effects on the environment, as well as supporting environment related ICT skills and education. If the computer scientists have to go green, a new awareness and culture have to be encouraged [31,382]. Promoting environmental-related ICT skills and awareness is the key for Green ICT and not for only a kind of green washing.

As a software developer you should be aware that relying on the availability of cheap hardware capacity on the user's side is ecologically expensive, because it boosts hardware flow. Avoid software-induced hardware obsolescence (SIHO) [2,3,27,25].

The variety of user needs has to be dealt with through conceptual clarity. Even an infinite variety can be generated from a finite set of well-defined concepts and principles. If software functionality were presented in an 'axiomatic' style instead of an 'additive' style, its complexity would be masterable. Remember to "*avoid unmastered complexity*" (E. W. Dijkstra).

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