Green Computing and Sustainability

Anne-Cécile Orgerie

Green Computing and Sustainability

Anne-Cécile Orgerie*

**CNRS, IRISA, Rennes, France, anne-cecile.orgerie@irisa.fr*

Keywords: green computing, ICT, sustainability, cloud computing.

Abstract
Information and Communication Technologies (ICT) are an indispensable tool in our every-day life. The number of connected devices is rapidly increasing, along with their capabilities. However, such a growth leads to worrying electricity consumption. Green computing and networking aim at reducing the impacts of ICT on the environment. In this talk, we will attempt to quantify the ICT impacts and then review the main state-of-the-art propositions for sustainable computing.

Les technologies de l'Information et de la Communication (TIC) sont devenues indispensables dans notre vie de tous les jours. Le nombre d'équipements connectés augmente rapidement, tout comme leurs capacités. Cependant, cette croissance entraîne une consommation électrique inquiétante. L'informatique verte vise à réduire les impacts des TICs sur l'environnement. Dans cet exposé, nous essaierons de quantifier les impacts des TICs, puis nous présenterons les techniques principales de la littérature pour une informatique durable.

Introduction
Sustainability aims at guaranteeing to present and future generations the capability to meet their own needs. Towards this end, Information and Communications Technologies (ICT) are often cited as a major lever to reduce the energy consumption and greenhouse gas emissions of other industry fields [1]. They are indeed able to optimize and automate industrial processes, but also to offer new innovative solutions. For instance, the usage of ICT can limit transportation - which is a huge greenhouse gas emitter – through videoconferencing, that reduce human travels, and through car-sharing websites, that optimize them. From online journals to smart building, ICT is progressively invading most of the industries, and often with an ecological argument. This trend, termed as *ICT4Green* or *ICT4 Sustainability*, includes smart buildings, smart grids, smart cities, etc. However, ICT consumes itself substantial amounts of electricity and is responsible for weighty greenhouse gas emissions. Consequently, exploiting ICT capabilities to come to the rescue of other industries' sustainability leads to rebound effects that can lower – or even reverse – their benefits [2]. The complexity of the connection between ICT and sustainability comes from the fact that ICT devices can be both actors and consumers at the same time, and thus, they also need to turn green. In this paper, we will explore this complex relation by first looking at the current energy consumption of ICT. Then, we indicate several state-of-the-art ways of greening ICT. Finally, we conclude by presenting the arduous challenge of having an overall view of the potential levers enabling a greener ICT.

1. Current situation: ICT energy consumption
According to the abundant literature on the subject, ICT industry would account for 2 to 10 percent of global CO2 emissions [3,4]. The various studies dealing with this complex evaluation do not agree on an exact number to measure ICT impact. As a comparison, aviation is estimated to represent 2% of global CO2 emissions. However, one can notice that, firstly, aviation growth is slower than the increase of ICT industry, and secondly, aviation is not considered as a 'green' industry.

The same complexity can be observed while looking for an evaluation of the global energy consumption of ICT. The consensus resides around 5% [5]. Currently, for this global energy consumption, the following breakdown is observed: approximately one third for data centers, one third for communication networks and one third for user equipment (computers, monitors, etc.) [5]. Each portion is complex to compute due to the rapid adoption of new ICT devices, the blurred frontiers between these three categories, and the diversity of technologies used in ICT which do not have identical impacts in terms of electricity consumption – wireless and wired telecommunication technologies for instance. As an example, in 2013, Coroama and Hilty reviewed the literature to assess Internet energy intensity, and found that: "Estimates published over the last decade diverge by up to four orders of magnitude — from 0.0064 kilowatt-hours per gigabyte (kWh/GB) to 136 kWh/GB" [6].

Around 2008, however, the emergence of Cloud computing promised a massive mutualization of servers through isolation and co-location of multiple virtual machines on the same physical server. In addition, advances in multicore architectures have improved the energy efficiency of servers: for the same calculation, less energy is needed. However, ICT followed the Jevons paradox (rebound effect), formalized in 1865 about coal: increasing the efficiency with which a resource is used leads to an increase of its total consumption because, in the same time, this improved efficiency reduces its relative cost, thus accelerating its economic growth. Indeed, in spite of significant improvements in its energy efficiency, the energy consumption of ICT has continued to increase from 3.3% to 4.7% between 2007 and 2012 [5].

In 2011, Greenpeace estimated that, if cloud computing were a country in 2007, it would have ranked 5th in electricity usage, placing itself between Japan and India [7]. Cloud computing relies on numerous data centers and a wide range of telecommunication networks, both private and public, to deliver on-demand, self-service, configurable and shared computing and storage resources. Through its virtual resources, it delivers Cloud services such as video sharing, online administrative tools, or multiplayer online games.

For the end-user, it is difficult to grasp the energy consumption of the virtual Cloud resources she uses: these resources seem invisible and are often free of charge (Facebook, Twitter, Gmail, etc.). However, the information appetite of Big Data, big networks and big infrastructure unavoidably leads to big power [4]. In 2012, it was estimated that, each day, 145 billion emails were exchanged, 4.5 billion searches were launched on Google, 104,000 hours of video were uploaded on Youtube, and 40,000 gigabytes of data were produced at the Large Hadron Collider [8].

Such widely used Cloud services are supported by gigantic infrastructures. As an example, for 2010, Google used 900,000 servers and consumed 1.9 billion kWh of electricity [9], and the power demand of a single datacenter can reach up to 100 MW [7]. In 2012, the number of data centers worldwide was estimated at 509,147 consuming roughly the output of 30 nuclear power plants [10]. On the other side, it is estimated that in 2017, Internet users will rely on an average of 5 connected devices per person, with more than 20 billion devices connected [11]. All portions of ICT technologies seem concerned by this inexorable energy consumption growth. The urgency of the situation calls for significant improvements and changes, in particular in users' habits. While this last point appears arduous, research in green computing has delivered interesting pathways to make ICT more sustainable.

2. Towards greening ICT

Energy has always been a matter of concern in certain domains of ICT, like sensor networks and battery-constrained devices. However, for other ICT systems, like data centers, it has only recently become an issue [12]. The Gartner's annual hype cycle for emerging technologies [13] shows this phenomenon: green IT first appeared in 2008, directly at the peak of the wave; in 2009 it was on the declining side of the wave, and surprisingly by 2010 it had disappeared. Reducing energy consumption of ICT devices is a challenging issue that should be addressed at different levels: hardware, software and user levels.

2.1. Improving energy-efficiency

In order to improve energy-efficiency, it is necessary to identify the biggest consumption items for each ICT field. For instance, in data centers, cooling systems are typically estimated to consume 33% of the total value [14]. A green evolution consists in using free cooling: using outside air to cool servers. This technique leads companies to locate their facilities in regions and countries with cold climate, such as Sweden, Finland or Iceland [15].

Energy savings can be made at all the hardware levels: from processor chips to data center infrastructures. The energy-efficient design of low-power processors or the use of dedicated hardware (e.g. Graphics Processing Unit) can reduce the energy cost per operation [16].

Energy efficiency indicators were defined to characterize data centers. The most common is the PUE (Power Usage Effectiveness) introduced by the Green Grid consortium in 2006 [17]. It is determined by the ratio of the total energy consumed by the center and the part consumed only by the 'useful' facilities: server, storage and network. However, this indicator has two major drawbacks: it does not account for the actual use of computing and storage resources and does not take into consideration the origin of the energy consumed. Large data centers manufacturers no longer hesitate to display their PUE and make his decline a commercial argument. For instance, Google shows that the average PUE from 1.21 in 2009 to 1.12 in 2016 [18].

Green computing has also benefitted from several standards and regulations. Tangible efforts have been made on the energy consumption of ICT equipment (EnergyStar standard for reduced consumption in standby and off appliances, 80plus for energy-efficient power supplies) and the restrictions of hazardous substances utilization (European directives RoHS, REACH). Other work, not from the legislative side but rather on the recommendation should also be mentioned, like the European Code of Conduct on Data Centres that advise infrastructure admins to have greener habits, by increasing the data center room's temperature for instance [19].

It seems that only regulations and norms can fight against certain bad manufacturing practices, in particular practices leading to obsolescence: when a device is replaced although it is still in good working state. This happens when the device is exceeded due to software evolution. For example, the end of Windows XP support is effective since 2014. This means that computers with this operating system will become potentially vulnerable to new security vulnerabilities and cannot be used without safety risks. According to a survey conducted in March 2016, 11.24% of computers worldwide, roughly 200 million computers, are still using Windows XP [20].

A similar issue appears when the spare parts required for the repair of a device are no longer available: the device must be entirely replaced. This is the case for example if a computer keyboard key is deficient, the keyboard must be changed; or when the battery on a laptop is welded to its structure and thus cannot be easily replaced. It would be preferable to have a more modular design of devices and increase availability of spare parts.

2.2. Increasing resource utilization

In addition to improve energy-efficiency, it is also required to increase resource utilization in order to reduce energy waste. Indeed, unused but powered-on resources consume non-negligible amounts of electricity. In 2010, the Green Grid consortium carried out a survey about unused servers in 188 data centers, mostly located in the United States [21]. They estimate that on average 10% of the servers are never used, hence wasting energy.

Another study conducted in 2008 shows that data center server utilization rarely exceeds 6% [22]. As the energy consumption of servers is not proportional to their workload [12], they consume large amounts of energy even when not in use but simply powered-on – 40 and 60% of their maximum consumption when fully loaded [12]. It is therefore vital that these servers have standby capabilities (more energy-efficient mode) and remote wake-up mechanisms, in order to adapt the computing capacity on users' demand.

Two approaches are commonly employed to reduce this energy waste: sleeping techniques and slow down techniques [12]. The first one consists in putting to sleep or standby mode unused resources, and uses remote wake-up mechanisms such as IPMI (Intelligent Platform Management Interface). This is a standard hardware that operates independently from the operating system and allows administrators to manage a system remotely through a direct connection. This interface can also be used to switch nodes on and off remotely.

The sleeping mode usage can be increased with consolidation algorithms consisting in resource allocation policies gathering workload on the fewer number of resources required to support it without performance degradation [12]. Such algorithms greatly benefit from virtualization capabilities, such as virtual machine isolation and live migration. Indeed, by migrating virtual machines between different physical servers, it creates empty servers which can be put into sleep modes.

The slow down technique for processors is called DVFS (Dynamic Voltage and Frequency Scaling) and gives processors the ability to adjust their working frequency and power consumption to save energy [12]. It is then necessary to implement smart algorithms to decide when and how to switch between the available processor frequencies depending on the workload.

Software also does not escape to the ever-growing energy needs, needs that are increased by the multiplication of available applications. In 2014, a survey shows that smartphone owners have an average of 35 installed applications, of which only 11 are used every week and 12 are never used, and this number has increased since the previous study [23]. However, all these installed applications consume computing and storage resources. Indeed, an application that is never used can be programmed to send periodic notifications to remote servers (e.g. location data) and thus have a significant energy consumption.

Software eco-design consists in optimizing their environmental footprint and allows real energy gains. It relies on the use of more energy-efficient algorithms, reducing execution time (and thus CPU utilization), developing precise specifications to eliminate unnecessary features and optimization of generated data volumes. For example, a modification of the mobile version of the Wikipedia website scripts reduces by 30% the energy needed to download and render its webpages. One should go back to software practices of the time when code was optimized because of the high cost of resources available on the market (RAM, processor speed).

2.3. Increase users' energy-awareness

Unlike in the case of data centers, the user can act directly on the software and devices she uses, and therefore, has a key role to play in reducing the ICT impact on sustainability. However, this requires her to be informed of the available levers available she has access to, and the actual consumption of her applications. Some software tools provide real time measurements or estimations of the energy consumption of processors, such as the Intel Power Gadget [24]. It would be interesting to extend its functionalities, so that users could estimate the energy consumption of each of their applications including all resources used (CPU, memory, network card, hard drives, etc.).

The PowerTOP [25] software (for Linux) goes even further in this direction: it allows a diagnosis of the energy consumption of a computer; it provides configuration tips to reduce consumption and offers an interactive mode in which the user can test different configurations of her system. Such software can provoke a real awareness of users regarding their impacts associated with ICT on electricity consumption. As such, the approach proposed by this software would deserve to be extended to other energy-consuming electronic devices (monitors, smartphones, etc.) and could thus promote user empowerment.

Increasing energy-awareness of users could also allow service providers to save energy by offering different options to users. For instance, a user could accept to wait a given amount of time for its service to be executed if she is informed that waiting will save a certain amount of energy because her request will be consolidated with other requests for instance. Or a scientific user could slow down her application in order to save energy if she knows that she will still get her results before her deadline.

Such a system, offering different options to the user and displaying a clear trade-off between energy saving and performance degradation, can save significant amount of energy [26]. A user could also be willing to delay her request processing in order to benefit from renewable energy sources [27]. In the case of specific collaborative applications, a user could also accept to host on her own device part of the computing system for processing requests from her neighbors and thus, saving energy in the telecommunication networks needed to connect each user to the service provider [28]. However, in all these techniques, energy-awareness of the users may be insufficient for adopting energy-aware behavior and adequate incentives (financial or motivational) need to be proposed to ensure the success of such approaches. For instance, a carbon tax may encourage users to wait for renewable energy availability, or an added social value may incite users to buy greener services or products like the Fairphone – a smartphone designed and produced with high sustainability criteria [29].

3. The whole loop challenge

Finally, we think that the main issue in greening ICT resides in the whole loop challenge: to take into account all the parameters required to ensure substantial energy savings. For instance, when a user submits a Google request from a connected device (such as a search for instance), it is routed to a data center that processes it, computes the answer and sends it back to the user. Google owns several data enters spread across the world. For performance reasons, the center answering the user's request is more likely to be the one closest to the user. However, this data center may be supplied by a far away energy source. A more distant data center may be using a renewable energy source, which happens to be close by and available at the time of the request. This request may have consumed less energy, or a different kind of energy (renewable or not), if it had been sent to this further data center. In this case, the response time would have been increased but maybe not noticeably: a different trade-off between performance and energy-efficiency could have been adopted [30]. Taking into account only the computing costs leads to proposing optimization algorithms that do not optimize the overall energy consumption, but only the consumption of one data center. Indeed, network resources account for a non-negligible part in the energy equation [30]. Moreover, as seen in Section 2.1, cooling units are an important energy consumption factor; they should thus be taken into account when balancing the load among several data centers.

On the other side, considering only the usage phase of the ICT equipment is biased, as other life-cycle phases can be more consuming. For instance, a use phase of 5 years of a typical server can constitute only half of the CO2 emissions of its entire life cycle: its manufacturing and its distribution completes the other half [31]. Concerning the impact on greenhouse gas emission, life-cycle assessment shows that for servers, the use phase is dominating. However, in terms of user devices (computers, tablets, smartphones, etc.), the manufacturing phase is significantly more impactful than the use phase in France [32].

One can wonder if we are going the good way: ancient telephone receivers were only connected to the telephone network. They did not require to be connected to the power grid, while current smartphones require their batteries to be recharged every few days. Smartphones are indeed offering new functionalities compared to old phones, but one can wonder these new functionalities, which creates new practices, do not also generate new needs, a multiplication of devices with an important capability overlap between these devices, and in the end, an alarming and unnecessary increase in global energy consumption. Moreover this phenomenon is racing fast: we exceeded 1.4 billion smartphones sold in one year in 2015, an increase of almost 10% compared to 2014 [33] and, in 2015, the average life duration of first-hand smartphones before replacement fell under two years.

In order to reduce ICT energy consumption, we could limit its utilization, as proposed in [34]. However, the enforcement of such an idea would probably require strict international regulations. Currently, to our mind, raising the energy-awareness of users seems to be the only sustainable way of greening ICT.

Acknowledgement

The author would like to thank Françoise Berthoud, Eric Drezet and Laurent Lefèvre who co-authored the article entitled "*Sciences du numérique et développement durable : des liens complexes*" on the Interstices online journal available here: https://interstices.info/jcms/p_84005/sciences-du-numerique-et-developpement-durable-des-liens-complexes in 2015; this article greatly inspired this paper.

References

1- John A. Skip Laitner, "The energy efficiency benefits and the economic imperative of ICT-enabled systems", in ICT Innovations for sustainability, L.M. Hilty, and B. Aebischer, Eds. Springer, 2015, pp. 37-48.

2- Cecilia Hakansson and Göran Finnveden, "Indirect Rebound and Reverse Rebound Effects in the ICT-sector and Emissions of CO2", International Conference on ICT for Sustainability (ICT4S), 2015.

3- Gartner, **"**Gartner Estimates ICT Industry Accounts for 2 Percent of Global CO2 Emissions**"**, Gartner online article, http://www.gartner.com/newsroom/id/503867, 2007.

4- Mark Mills, "The Cloud Begins With Coal", Digital Power Group report, http://www.tech-pundit.com/wp-content/uploads/2013/07/Cloud_Begins_With_Coal.pdf?c761ac, 2013.

5- Académie française des technologies, "Impact des TIC sur la consommation d'énergie à travers le monde", report,

EDP Sciences, 43 pages, http://www.academie-technologies.fr/blog/posts/impact-des-tic-sur-la-consommation-d-energie-a-travers-le-monde, 2015.
6- Vlad C. Coroama, and Lorenz M. Hilty, "Assessing Internet energy intensity: a review of methods and results", Environmental Impact Assessment Review, vol. 45, pp 63–68, 2014.
7- Greenpeace, "How dirty is your data?", Greenpeace report, 2011.
8- Fabrice Demarthon, Denis Delbecq, and Grégory Fléchet, "The Big Data Revolution", CNRS International Magazine, http://www.cnrs.fr/fr/pdf/cim/CIM28.pdf, December 2012.
9- Jonathan Koomey, "Growth in Data Center Electricity Use 2005 to 2010", Analytics Press, August 2011.
10- James Glanz, "Power, Pollution and the Internet", The New York Times, September 2012.
11- Forrester Research, "Connected devices forecast, 2012 to 2017", white paper, 2013.
12- Anne-Cécile Orgerie, Marcos Dias de Assunção, and Laurent Lefèvre, "A Survey on Techniques for Improving the Energy Efficiency of Large Scale Distributed Systems", ACM Computing Surveys, 46(4), 2014.
13- Gartner, "2010 Emerging Technologies Hype Cycle is Here", http://blogs.gartner.com/hypecyclebook/2010/09/07/2010-emerging-technologies-hype-cycle-is-here/, 2010.
14- Albert Greenberg, James Hamilton, David Maltz, and Parveen Patel, "The Cost of a Cloud: Research Problems in Data Center Networks", ACM SIGCOMM Computer Communication Review, 39:68–73, 2008.
15- Michael Pawlish and Aparna Varde, "Free cooling: A paradigm shift in data centers", International Conference on Information and Automation for Sustainability (ICIAFS), pages 347–352, 2010.
16- Balaji Subramaniam, Winston Saunders, Tom Scogland, and Wu-chun Feng, "Trends in Energy-Efficient Computing: A Perspective from the Green500", in International Green Computing Conference, June 2013.
17- Gemma Brady, Nikil Kapur, Jonathan Summers, and Harvey Thompson, "A Case Study and Critical Assessment in Calculating Power Usage Effectiveness for a Data Centre", Energy Conversion & Management, 76: 155-161, 2013.
18- Google Data Centers, "Efficiency : How we do it", online: http://www.google.co.uk/about/datacenters/efficiency/internal/#measuring-efficiency, access March 2016.
19- European Commision, "Data Centres Energy Efficiency", Code of Conduct, version 3.1.2, http://iet.jrc.ec.europa.eu/energyefficiency/ict-codes-conduct/data-centres-energy-efficiency, 2016.
20- Net Market Share, "Desktop Operating System Market Share", online: https://www.netmarketshare.com/operating-system-market-share.aspx, access March 2016.
21- Mark Blackburn and Andy Hawkins, "Unused Servers Survey Results Analysis", The Green Grid report, http://www.thegreengrid.org/~/media/WhitePapers/Unused%20Server%20Study_WP_101910_v1.ashx?lang=en, 2010.
22- James Kaplan, William Forrest and Noah Kindler, "Revolutionizing Data Center Energy Efficiency", McKinsey & Company report, http://www.sallan.org/pdf-docs/McKinsey_Data_Center_Efficiency.pdf, July 2008.
23- Harris Interactive, "Usages & attitudes vis-à-vis des applications mobiles", survey, http://harris-interactive.fr/opinion_polls/usages-attitudes-vis-a-vis-des-applications-mobiles/, March 2014.
24- Intel, "Intel Power Gadget, software", version 3.0, https://software.intel.com/en-us/articles/intel-power-gadget-20, 2014.
25- Powertop, software, version 2.8, https://01.org/powertop, 2015.
26- David Guyon, Anne-Cécile Orgerie and Christine Morin, "Energy-efficient User-oriented Cloud Elasticity for Data-driven Applications", GreenCom: IEEE International Conference on Green Computing and Communications, December 2015.
27- Yunbo Li, Anne-Cécile Orgerie and Jean-Marc Menaud, "Opportunistic Scheduling in Clouds Partially Powered by Green Energy", GreenCom: IEEE International Conference on Green Computing and Communications, December 2015.
28- Ismael Cuadrado Cordero, Anne-Cécile Orgerie and Christine Morin, "GRaNADA: A Network-Aware and Energy-Efficient PaaS Cloud Architecture", GreenCom: IEEE International Conference on Green Computing and Communications, December 2015.
29- Somya Joshi and Teresa Cerratto Pargman, "On Fairness & Sustainability: Motivating Change in the Networked Society", International Conference on Informatics for Environmental Protection (EnviroInfo), 2015.
30- Anne-Cécile Orgerie, "Interconnecting Smart Grids and Clouds to Save Energy", SMARTGREENS: International Conference on Smart Grids and Green IT Systems, May 2015.
31- Fujitsu, "Fact Sheet: CO2-Footprint of a Desktop-PC ESPRIMO E9900", report, http://sp.ts.fujitsu.com/dmsp/Publications/public/pos-co2-footprint.pdf, 2010.
32- Françoise Berthoud, Eric Drezet, Laurent Lefèvre and Anne-Cécile Orgerie, "Sciences du numérique et développement durable : des liens complexes", Interstices, https://interstices.info/jcms/p_84005/sciences-du-numerique-et-developpement-durable-des-liens-complexes, 2015.
33- Anthony Scarsella and William Stofega, "Worldwide Smartphone Forecast Update , 2015-2019", IDC report, http://www.idc.com/getdoc.jsp?containerId=US40734415, December 2015.
34- Kris De Decker, "Why We Need a Speed Limit for the Internet", Low-Tech Magazine, http://www.lowtechmagazine.com/2015/10/can-the-internet-run-on-renewable-energy.html, October 2015.