CEPIS UPGRADE is the European Journal for the Informatics Professional, published bimonthly at <http://cepis.org/upgrade>

Publisher
CEPIS UPGRADE is published by CEPIS (Council of European Professional Informatics Societies, <http://www.cepis.org/>), in cooperation with the Spanish CEPIS society ATI (*Asociación de Técnicos de Informática,* <http://www.ati.es/>) and its journal Novática

CEPIS UPGRADE monographs are published jointly with Novática, that publishes them in Spanish (full version printed; summary, abstracts and some articles online)

CEPIS UPGRADE was created in October 2000 by CEPIS and was first published by Novática and INFORMATIK/INFORMATIQUE, bimonthly journal of SVI/FSI (Swiss Federation of Professional Informatics Societies)

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Cover page designed by Concha Arias-Pérez
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ISSN 1684-5285

Monograph of next issue (December 2011)
"**Risk Management**"

CEPIS UPGRADE

The European Journal for the Informatics Professional
http://cepis.org/upgrade

Vol. XII, issue No. 4, October 2011

Monograph
Green ICT: Trends and Challenges
(published jointly with Novática*)
Guest Editors: *Juan-Carlos López-López, Giovanna Sissa, and Lasse Natvig*

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* This monograph will be also published in Spanish (full version printed; summary, abstracts, and some articles online) by **Novática**, journal of the Spanish CEPIS society ATI (*Asociación de Técnicos de Informática*) at <http://www.ati.es/novatica/>.

Utility Computing: Green Opportunities and Risks

Giovanna Sissa

A visionary idea of computing since the early 60s has been that of utility. Cloud computing finally looks to be the implementation of such an idea. While this paradigm is providing many opportunities for the development of the software sector, concerns about its environmental impact are also being raised. This paper focuses on the green potential of clouds and how they have to be deployed for different user levels, highlighting the related environmental risks. The trend shows clearly how cloud computing is turning computing into a pay-per-use model, one in which quality of service requirements will need to be expanded to include green requirements. Green computing has to take into consideration new opportunities and new issues for the environment, not only focusing on the energy use phase but also on all phases of the life cycle for any service provided in the cloud. The awareness of users and developers is the first step to realizing the green potential of the cloud.

Keywords: Cloud Computing, Green ICT, Life Cycle, Quality Of Service Requirements, Reuse, Utility Computing.

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1 Back to the Future: Computing as Utility

In the 60s computers were as big and expensive as they were difficult to use and maintain. Computational centers had to have human operators as an interface between users and the computer. Users wrote their programs on a set of punch cards and in order to run them they had to contact the computer center operator to give him the packaged cards and pay for computation time. The model was pay-per-use of the computing resource.

One of the stronger ideas underlying the development of computing has always been that computing should be a utility, like water, electricity, gas, or telephony. To became true, this dream would have needed the availability of computing everywhere. At that time, there was no possibility of computing joining the ranks of other kinds of utilities, because of the lack of a "pipeline" for computing resources.

But the computing model evolved in the opposite direction: towards individual availability, at home or at the office, of the computer itself, i.e. the personal computer. In the PC paradigm the user has become the owner of computing capability, which he or she manages.

With the Internet it soon became clear that something was changing. As early as 1969, Leonard Kleinrock [1], one of the chief scientists at ARPANET, said "*As of now, computer networks are still in their infancy, but as they grow up and become sophisticated, we will probably see the spread of computer utilities which, like present electric and telephone utilities, will service individual homes and offices across the country*". The pipeline issue could be solved.

The vision of computing utilities based on a "service provisioning model" anticipated the cloud computing era, in which computing services are readily available on demand, just like other utilities, and users need to pay providers only when they access them.

2 Cloud Computing Opportunities

In the ICT sector, cloud computing is one of the most searched terms. There are a great many definitions, but none which is fully accepted by the scientific community as a whole.

The NIST (National Institute of Standards and Technology) definition is very broad: "*Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. This cloud model promotes availability and is composed of five essential characteristics, three service models, and four deployment models*" [2].

In September 2011Wikipedia defines cloud computing as follows: "*Cloud computing is the delivery of computing as a service rather than a product, whereby shared resources, software and information are provided to computers and other devices as a utility (like the electricity grid) over a network (typically the Internet)*".

Cloud computing delivers infrastructure, platform and software applications as a service, which are made available to consumers as subscription-based services under the pay-per-use model.

> “This paper focuses on the green potential of clouds and how they have to be deployed for different user levels, highlighting the related environmental risks”

And within each layer of abstraction there are myriad opportunities for defining the services that can be offered [3]. Users can access and deploy applications from anywhere in the world, on demand, and at a competitive cost depending on their quality of service requirements. QoS requirements are specified to users via Service Level Agreements (SLA).

The need to manage multiple applications in a datacenter creates the challenge of **on-demand** resource provisioning and allocation in response **to time-varying workloads**. This feature, called elasticity, is one of the five cited by NIST: *"Capabilities can be rapidly and elastically provisioned, in some cases automatically, to quickly scale out, and rapidly released to quickly scale in. To the consumer, the capabilities available for provisioning often appear to be unlimited and can be purchased in any quantity at any time*" [2].

In other words, cloud computing refers to both the applications, delivered as services over the Internet, and the hardware and systems software in the datacenters that provide those services. The datacenter hardware and software is what we will call a Cloud. When a Cloud is made available in a pay-per-use to the general public, we call it a **Public Cloud;** the service being sold is **Utility Computing** [4].

If cloud computing is finally the implementation of the old idea of "computing as a utility" [5], what are the implications arising from it? The answer depends on whoever is posing the question.

The meaning of cloud computing is different for different people, depending on their use of the cloud. For application user it is the delivery of computing, storage and application over the Internet from centralized datacenters. For Internet application developers it is an Internet-scale software development platform and runtime environment. For infrastructure providers it is the massive distributed datacenter infrastructure connected by IP network [6].

The cloud has been a boon for the companies hosting it.

Developers no longer need to invest heavily or go to the trouble of building and maintaining complex IT infrastructures. Developers with innovative ideas for new Internet services no longer require large capital outlays in hardware to deploy their service.

Thus the computing world is rapidly transforming towards the development of software for millions to consume as a service rather than to run on individual computers [5]. The network is the platform for all computing, where everything we thought of as a computer yesterday is just a device that connects to the internet [7].

If cloud computing represents plenty of opportunities for different kind of users, what opportunity does it represent for the environment? What does the implementation of utility computing mean from an environmental point of view? Does it represent a major opportunity? Or are there also some risks concerning sustainability? Is cloud computing green computing?

3 Green Computing

Green computing is an umbrella term that includes the dimensions of environmental sustainability, the economics

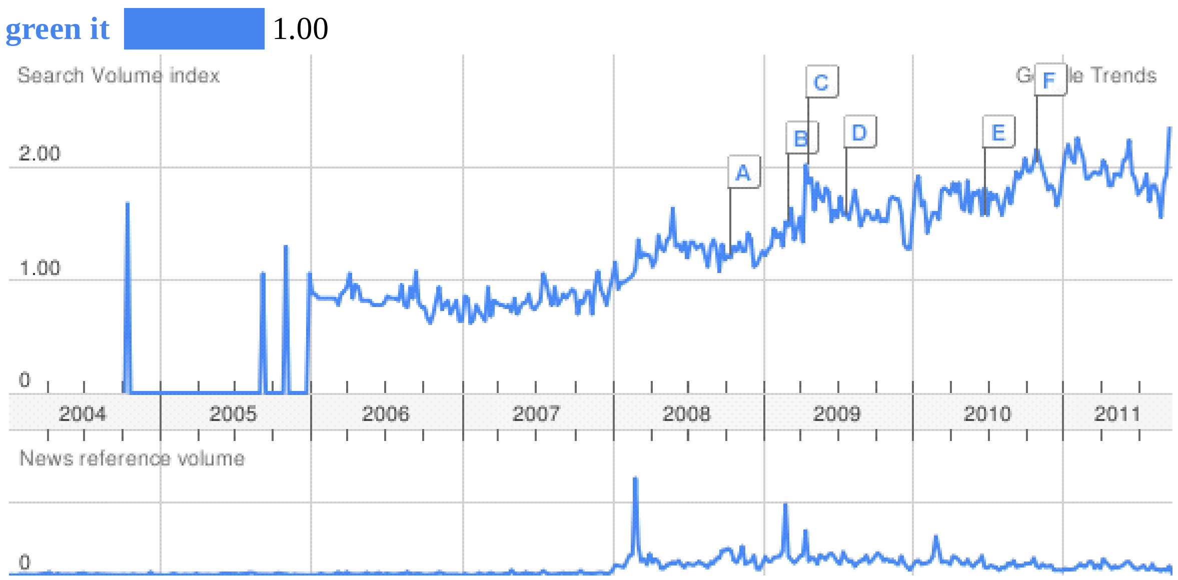

Figure 1: Green IT in Google Trends.

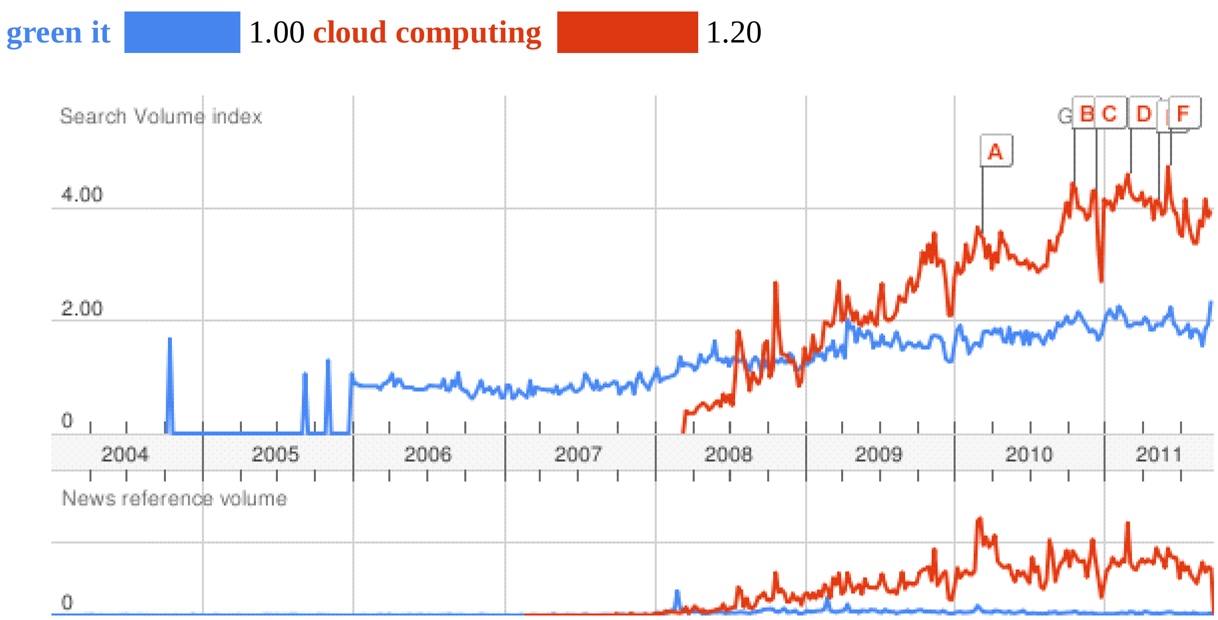

Figure 2: Comparison between Green IT and Cloud Computing in Google Trends.

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 greenhouse gas emissions, using less harmful materials, and encouraging reuse and recycling [8].

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

Corporations and their IT departments are recognizing the impact of their "carbon footprint" on the environment, and if we make a Google Trends search we can see how the popularity of the term is growing.

A query on "green IT" (Figure 1) shows a growth of the interest.

It's interesting to make a comparison between the term 'green IT' and the term 'cloud computing' (Figure 2).

Given the growing importance of cloud computing, the question is not whether it is green as it is now, but how it can became really green. The focus will be on the potential green role played by cloud computing as an implementation of utility computing.

Strongly driven by the hardware producers, green computing supplies a huge offer of green ICT devices and products. But, since the computing paradigm has shifted towards cloud computing, i.e. utility computing, the green challenge of ICT will be played out more and more on such a paradigm.

Before going into the green potential of cloud computing in greater depth, we have to remember some basic environmental sustainability principles related to the ICT sector and then try and apply them to cloud computing.

4 Cloud Computing and First Order Effects

In 2007 the total footprint of the ICT sector was 830 MtCO2 emissions, about 2% of the estimated total emissions from human activity released that year [9].

Adjustment to the Smart 2020 report have been suggested by environmental organizations [10], highlighting the scale of ICT's estimated energy consumption, and providing a new analysis of the projected growth in energy consumption of the Internet and cloud computing for the coming decade, particularly as driven by datacenters.

Each stage of a computer's life cycle, from its production, throughout its use, and on to its disposal, increases carbon dioxide emissions and the impact on the environment. The total electrical energy consumption by servers, computers, monitors, data communications equipment, and cooling systems for datacenters is steadily increasing. Data Center now produces more carbon emissions than both Argentina and the Netherland [2]. Google, Microsoft and Yahoo are building their datacenter near the Columbia river, to exploit cheap and reliable hydroelectric power. There is a trend emerging to build data farms in cold regions, like Iceland, to decrease cooling power needs and price. In other

“Given the growing importance of cloud computing, the question is not whether it is green as it is now, but how it can became really green”

> “What is the hypothetical footprint of a startup that may have chosen to build its own datacenter versus using cloud computing?”

words, there are a lot of nested relationships between ICT and the environment.

ICT devices are becoming more and more compact and energy efficient and green computing is responsible for such improvements. New generation IT systems provide more computing power per unit of energy but, despite this, they are actually responsible for an overall increase in energy consumption. The demand for ICT is increasing even faster than the energy efficiency of ICT devices [11]. This is because users are taking and using the increased computing power offered regardless of its effect on sustainability.

Moreover cloud computing is changing the way we quantify the direct effects of ICT, adding some additional issues about its measurability. The shift toward cloud computing looks, in principle, to be more environmentally friendly compared to traditional datacenter operational/deployment models. The rule of thumb says that a higher consolidation/optimization of the infrastructure will make it possible to conserve energy. But if cloud computing can *enable green*, and it could be a great way to reduce the carbon footprint, we have to be able to demonstrate it. And to demonstrate something you have to quantify it.

The emission factor, the rate for converting kilowatt-hours into units of carbon dioxide emissions, is the basis for any evaluation of the direct impact of ICT. This rate varies from country to country and from region to region because it depends on the source from which electric power is produced [12]. Power sources can have dramatically different CO2 footprints, say coal vs. wind or solar.

Industry adopted metrics (PUE, DCIE) take into consideration the efficiency of datacenter infrastructure relative to energy demand, but not to the overall resource impact or even the amount of energy needed for a particular computing activity. Metrics like PUE are valuable in helping datacenter operators to benchmark the design and efficiency of their facilities by providing an objective metric that drives effort to improve facility efficiency. Recent efforts have been made to develop additional resource-based metrics that speak to the carbon intensity (CUE) and water utilization (WUE) of a datacenter

All ICT-based services will increasingly be delivered on the cloud. When an ICT-based service is provided, it is responsible for a given amount of CO2 emissions. The challenge, from a green perspective, is to be able to quantify the per-unit energy consumption, and more generally, the per-unit carbon emissions. In particular the challenge is to quantify a service when it is delivered on the cloud.

Even as a rough estimate, the entire life cycle of the whole system providing a given service should be studied, in order to assess the environmental impact of producing one *functional unit* of the service. While it is quite straightforward to compare the CO2 emissions of a new generation tablet with those of a desktop computer, it is far from straightforward to compare the emission equivalence of a computing activity delivered traditionally or by the cloud.

In other words we have to be able to quantify the impact in terms of CO2 emission equivalent of an ICT-based service delivered on the cloud.

By definition clouds are promising to provide services to users without reference to the infrastructure on which these are hosted. As consumers rely on cloud providers for their computing needs, they have to require that a specific QoS (Quality of Service) will be maintained by their providers, in order to meet their objectives and sustain their operations [5]. While it is clear that there are critical parameters such as time, cost, reliability and trust/security, equally important are the parameters linked with the green performance of the cloud.

If we measure software quality with *software quality factors* which describe how software behaves in its system, from a green perspective we need new *green quality factors*. In particular we need green cloud computing factors allowing a uniform way to measure the supposed gain in efficiency allowed by the cloud.

5 Cloud Computing: Environmental Issues and Challenges

Cloud computing with increasingly pervasive front-end client devices interacting with back-end datacenters will cause an enormous escalation of energy usage. To address this problem, datacenter resources need to be managed in an energy-efficient manner to drive Green Cloud computing. In particular, cloud resources need to be allocated not only to satisfy QoS but also to reduce energy usage [13].

In order to test the green performance of the cloud we have to be able to answer such questions as: What is the hypothetical footprint of a startup that may have chosen to build its own datacenter versus using cloud computing?

Running the numbers about how green a particular usage scenario actually is becomes more complicated than showing green credentials. Moving on from the why in cloud computing to the how, claims regarding the green

> “Apart from a lack of transparency in the quantification of energy consumption by cloud providers, some other environmental risks can be envisaged”

credentials of cloud computing need to be clearly answered, motivated and calculated in order to substantiate those claims.

Common sense 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 reducing the carbon footprint, while higher DC consolidation / optimization will conserve energy.

The IT industry points to cloud computing as the new, green model for our IT infrastructure needs, but few companies provide data that would allow us to objectively evaluate these claims. And quantifications may not be comparable, because different cloud computing provides different service features and has incompatible starting assumptions.

Some concerns are also emerging within the cloud computing community [14][15]. We now have the ability to run our applications on thousands of servers, whereas previously this was not even possible. So we can potentially use several years' worth of energy in literally a few hours, while previously this was not even an option. So in direct contrast, hypothetically we are using more resources, not less.

On the flip side, if we bought those thousand servers and had them running (underutilized), the power usage would be significantly higher. You may use 80% less energy per unit, but you would have 1000% more capacity, which at the end of the day means you are using more energy, not less.

Apart from a lack of transparency in the quantification of energy consumption by cloud providers, some other environmental risks can be envisaged. That is because cloud computing encourages behavior that may not be very green [16].

The availability of cheap resources may encourage poor optimization.

The ability and ease of access to a massively abundant cloud computing resource will drive that behavior on the server. It will be cheaper to add 10 more web servers than to profile, optimize, regression test and deploy the code base.

Cloud computing allows things that may never have been processed before to be processed without an impact on performance, for example selecting a very large set of data for analysis (because you can literally process the data in an hour where previously it could take days).

If the cloud lowers the cost of providing services, it is possible to provide services that only generate a few pennies per transaction. While generally considered a benefit of the cloud, one has to question where the value of the end product is worth its environment cost. Another risk then is providing low value products and services.

The spread of mobile ICT is changing how we communicate, relate and manage our daily lives at an astounding speed. In 2011 the world will create a staggering 1.8 zettabytes[1] of digital information [17]. Think about the rate of increase in the number of people performing some sort of computation (for example, the hundred million members of Facebook all uploading photographs) and the rate of increase in the amount of data to be manipulated (consider a five megapixel camera built into everyone's phone,). All the while, in the cloud, processors will be running algorithms while constantly making adjustments as they **dynamically navigate** the trade-off between data size, connection speed, and client performance (as, for example, processor and screen resolution).

The question is, are we more environmentally friendly doing all of this on a shared cloud or at our own datacenters? Since the cloud allows our digital consumption to be largely invisible (and sometimes free of charge), we may fail to recognize that the information we receive actually devours more and more electricity.

The more compute cycles are available, the more we will use.

Awareness from developers is a precondition for a green behavior.

If cloud computing represents an extraordinary opportunity for developers, never seen before, able to decrease or fully eliminate the entry level in the application or services delivering on the Net, for the final user it is a new way of using the computer. Power-users, as well as simple-users are shifting from a computer-centered to an Internet-centered style. Consumers now need nothing but a personal computer and internet access to fulfill most of their computing needs. Personal applications are becoming available via Web, Google Docs being the best known example, an "Office Suite" in the Cloud, accessible anywhere, from any computer with a net connection and a decent browser. It is no longer mandatory to install the application on a personal computer!

Public awareness of climate change is increasing and the Cloud can be a good opportunity to achieve a greener ICT, in a broader sense, just by starting from end-user behavior. For example, by reducing the obsolescence rate of end-user devices, which are responsible for the major environmental problem called e-waste.

The cloud allows device-independence. It is possible to reuse the PC as a thin always-on client and to access our data and application everywhere. Old PCs can easily be turned into thin clients, further reducing equipment costs - the costs of operating system licenses and upgrades are reduced or even eliminated with open source software solutions [18]. Cloud computing can give end-users the opportunity to be free from a specific access device, traditionally their own PC, and to shift their working environment onto

“Awareness and responsible behaviors are a background condition to achieve sustainable and green cloud computing”

[1] 1 zettabyte = 1 trillion gigabyte = 10^{21} bytes.

a virtualized desktop. The critical infrastructure is broadband, not computing power.

6 Conclusion

Cloud computing is inherently green. To move to cloud computing appears to be more environmentally friendly compared with traditional datacenter operational/deployment models.

Many companies have been able to do away with the need for physical infrastructure and thus reduce their energy footprint. Thus, in some ways cloud computing can *enable green*, and could be a great way to reduce the carbon footprint. There are many advantages to this approach for both customers (lower cost, less complexity) and service providers (economies of scale). But there is also some risk for the environment as well. Awareness and responsible behaviors are a background condition to achieve sustainable and green cloud computing.

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