A Digital Infrastructure for Green Utility Computing: The Preliminary Holistic Research Agenda

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Abstract. The paper presents ICT environmental issues and discusses the transition towards green utility computing. Cloud services mainly based on virtualisation have a huge undiscovered yet potential to adequately address the issues of ICT to become greener alongside other economics (labour related costs such as people managing the ICT infrastructure). In order to outline the research agenda the paper includes a systemic / holistic analysis of the ICT development and usage as a pervasive/ubiquitous enabler in the daily life activities as well as different economic sectors (e.g. transportation, manufacturing, commerce, tourism etc.) and the increased environmental impacts. The main aim of this approach is the definition of a multi perspective research agenda for the development of an environmentally aware digital infrastructure to deploy green utility computing in the cloud. The increasing complexity of managing the whole infrastructure of platforms, people and services that transparently support ICT as a utility is also discussed. Some boundaries conditions are imposed.

Keywords: utility and cloud computing, virtualization, green/environmentally friendly ICT, energy efficiency, complex system and complexity, system dynamics.

1 Introductory Background

Environmental issues are emerging as important topics in the agenda of almost any technology advancement and associated debates. Several ICT vendors are becoming increasingly aware of the importance of producing environmentally friendly products. This is not surprising as the Global Action Plan (2009) supported by Logicalis, and the Environmental ICT showed that 2% of global carbon emissions are due to ICT [1]. An interesting aspect is that 98% of global carbon emissions require solutions [1] where ICT is expected to play an important role to support comprehensive environmentally aware approaches as described by Ghose et al. (2008) [2]. Indeed, ICT could support the energy efficiency and environmental awareness through intelligent systems enabling to reduce resource consumption, and power management. Xiao (2011) provided an approach for modeling and managing efficient power management of mobile technologies [3]. Other approaches suggested how new computing technologies

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including virtualisation and the cloud can be used for the realisation of the full spectrum of benefits of a distributed intelligent power management systems [4], [5]. Alternative solutions might apply the bio-inspiration alongside new technique such as cuckoo search. Generally, the application of ICT in intelligent systems for production and consumption of energy has the following impacts and directions that have provided the basis of the definition of key research questions:

Direct impact: Consumption of energy and non-renewable resources in the ICT sector and related products. How can a digital infrastructure materialised through software and hardware system become greener through the application of a wide range of methods as well as the new cloud computing paradigm? How could be minimised the negative environmental impacts of obsolete equipment?

Enabling solution: How can ICT reduce energy consumption in other sectors: using video conferencing instead of travelling, home work place, intelligent traffic systems, smart buildings, intelligent transportation management systems etc.? (as depicted in figure 2)?

Systemic Approach: Green ICT which generally, refers to the use of ICT resources in an energy-efficient and cost-effective manner particularly applying cloud computing and holistically analysed the resulted complex system. How can green ICT change the way we live and work and resulting in substantially reducing the production and consumption of energy? Is the social awareness through policies and regulations enough explained and directed to easing environmental issue and urge conservation?

How is it possible to develop systems metrics and use them?

At the same time more often than before moving from pervasive ICT office/home based applications to ICT as a utility is an obvious step forward. ICT as a utility or utility computing should be simple, accessible and reliable appearing invisible and providing easy and flexible access to computing resources that should be metered. There are similarities with other utilities, but in order to achieve the foreseen vision of IT becoming a utility (alongside water, gas, electricity, and telephone) different computing platforms (e.g. grids) have been proposed and analysed particularly, by Buyya et al. (2009) [6]. The full spectrum of consequences of achieving the vision of ICT as a utility should require an analysis and definition of a research agenda, short and long term challenges and a roadmap directed at providing recommendations for future research, development, implementation, deployment and adoption. For example, it should be considered that the use of ICT equipment especially obsolete is energy consuming and an increasing share of the energy consumption is desirable. Also recent studies demonstrated that carbon dioxide emissions from some data centres are increasing.

This paper discusses the systemic relationships between ICT development, pervasive support and the environmental issues with the main aim of defining a realistic research agenda for the identification of the design solutions of an environmentally friendly digital infrastructure for cloud or utility computing. The application of the cloud computing model that uses the virtualisation feature is at the core of this approach. Generally, virtualization is a technique for hiding the physical characteristics of computing resources to simplify the way in which other systems, applications, or end users interact with those resources. Virtualization, in essence is the ability to emulate hardware via software and it is used in some computing paradigms including cloud computing. Virtualisation is only one technology behind cloud computing development and new technologies might be even more beneficial for energy savings, reducing greenhouse emissions and related issues.

2 The Landscape of Green Utility ICT

2.1 Assessment of the Impacts of ICT on the Environment

A comprehensive review of the state-of-the art until 2007 of the impacts of electronic business and generally ICT on the environment has been provided by Yi and Thomas (2007) [7]. This review article presents the contents of various journal papers and thesis as well as other resources such as projects and associated reports, conference and symposia, and websites with the main aim of examining and capturing the most important approaches to date, either for a general knowledge of the area of the environmental impact and issue of extensive use of ICT. This background study could be used by experts carrying out future research and defining the directions of ICT as a utility matching the green computing requirements. This review highlighted that the dominant approach is either a micro-level case study or a macro-level statistical method and it is concluded that a more predictive and empirical model, which can be applied within different sectors should be more beneficial in the long term. Evaluations of the impacts of ICT on the environment have been made by different organisations including European Commission (EC) together with Joint Research Centre (JRC) [8] that have reported the future impacts of ICT on environmental sustainability. A complex system representing a set of implications of the application/use of ICT has been identified and it is presented in figure 1 that also has identified the systems boundaries.

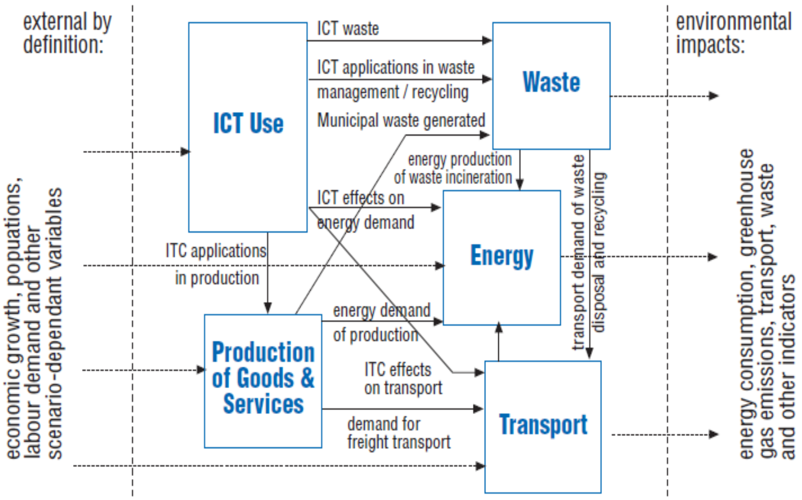

Fig. 1. Complexity and relationships of the Environmental Impacts of using ICT to different sectors [8]

The main outcome of this report has identified that the direct impact created by ICTs is negative, the overall impact on environmental sustainability may vary, depending on the applications and the aggregated effects of large numbers of people and organisations using ICTs. The UK's target is to reduce emissions by 80% by 2050 and by at least 34% by 2020. Large organisations such as public sector bodies or universities, where IT usage is extremely high find very difficult to reach these targets without adopting a fundamentally different approach in their IT energy strategy. If ICTs are to enable a decrease in absolute energy consumption, policy must also be designed in order to promote the environmentally positive impacts of ICTs, whilst inhibiting the negative ones [8].

Hilty et al. (2006) have developed a simulation study and a system dynamics model based on systems representation, relationships, and decomposition shown in figure 2. The simulation study combined scenario based demonstrations and expert consultations for analysing the positive and negative impacts of ICT on environmental sustainability [9]. The basic idea behind a systemic modeling approach has been the development of conceptual bridges from the use of ICT in different economic sectors to the environmental impact indicators (e.g. greenhouse emission, accounting for the following three types of ICT impacts or effects [9], [10], [11], [12]:

1. Primary impacts due to the effects of the physical existence and running of ICT (environmental impacts of the production, use, recycling and disposal of the hardware).
2. Secondary impacts to the indirect environmental effects of ICT due to its power to change processes (such as production or transport processes), resulting in a modification (decrease or increase) of their environmental impacts.
3. Low level impacts due to the environmental effects of the medium- or long-term adaptation of behaviour (e.g. consumption patterns) or economic structures due to the stable availability of ICT and the provided services.

However, due to some limitations of the system dynamics the results should not be interpreted as forecasting the development of the environmental indicators, because their absolute values in 2020 will greatly depend on the selected scenarios and on different parameters used for modeling that could not accurately capture the uncertainities. On the one hand, significant opportunities for improving environmental sustainability are in the potential impact of ICTs on the rational use of heating energy, and the support of decentralized electricity production from renewable sources and its important role in the product-to-service paradigm shift. On the other hand, ICT applications that make freight and passenger transport more time efficient (cheaper or faster) will immediately create more traffic and possibly more energy consumption. There is no empirical evidence for assuming anything other than a strong price rebound effect here, which could have severe environmental consequences in terms of energy use and greenhouse gas emissions (GHG).

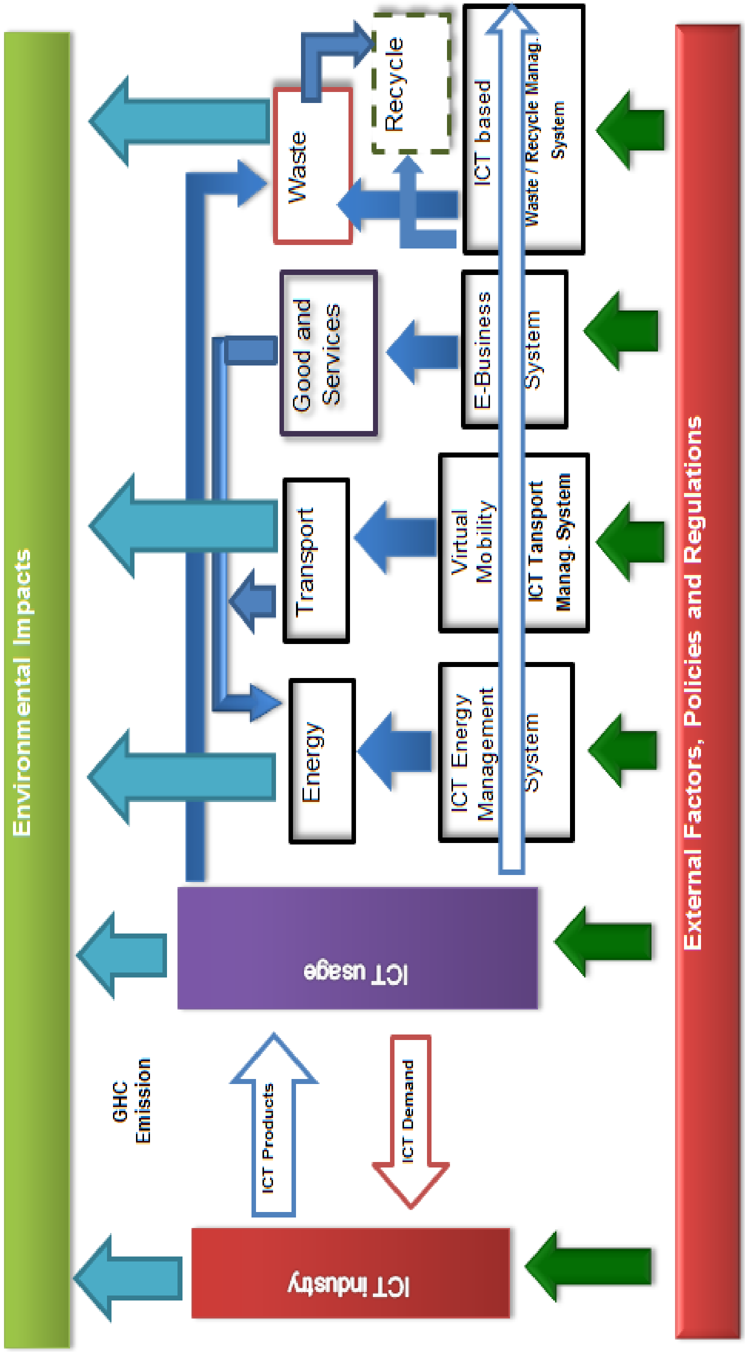

Fig. 2. Environmental Awareness System Representation based on [9]

2.2 Exploring the Vision of Green Utility Computing Model

The challenge of any research is not to just recognise the issues, but to know what can be done, how it can be done, and to identify certain solutions or at least directional recommendations towards solutions.

It is not enough to know that ICT being pervasive has been changing our lives, and different sectors of the economy such as manufacturing, business and transportation sectors. Implementing and operating utility computing might change even more, and ultimately an integrated approach which can influence the practices through environmental policies of green ICT of an organisation is needed. Bose and Luo (2011) have defined from the theoretical perspective a framework for the assessment of the potential of the organisation to undertake green ICT initiative especially using virtualization and cloud computing. This framework considers the organisational, technological and environmental perspectives attempting to create synergies that will increase the likelihood that companies will successfully implement green utility computing initiatives [13].

3 ICT as a Utility in the Cloud

3.1 Why Cloud Computing for Utility Computing?

Cloud computing has the foundation in distributed computing implemented usually using service oriented architecture and grid computing [14], [15]. Buyya et al. (2009) have provided the following description [6] “A cloud is a type of parallel and distributed system consisting of a collection of inter-connected and virtualized computers that are dynamically provisioned and presented as one or more unified computing resource(s) based on service-level agreements established through negotiation between the service provider and consumers." The distributed computing and mobile technologies have been already experimented for utility computing and these cover the essential requirements of utility computing. Moreover the National Institute of Standards and Technologies (NIST) has emphasized the elasticity feature of computing resources in their definition of cloud computing [16] that is largely accepted and frequently cited. This definition is as follows: “Clouds are a large pool of easily usable and accessible virtualized resources (such as hardware, development platforms and/or services)”.

Cloud Computing has resulted from the convergence of Grid Computing, and computing services, and represents the contemporary trend towards the external deployment of ICT resources, such as computational power, storage or business applications, and obtaining them as services. These resources can be dynamically re-configured to adjust to a variable load (scale), allowing also for an optimum resource utilization that are needed for utility computing. This pool of resources is typically exploited by a pay-per-use model in which guarantees are offered by the infrastructure provider by means of customized Service Level Agreements [17]. Grace (2010) has made explicit the distinctions between clouds, service oriented architecture and grid computing [18]. However the delimitation line is very narrow and particularly, with grid computing. Also a cloud infrastructure can be defined on service orientated architectures by adding a layer of virtualization and self- provision. On the other hand a service architecture could be built on clouds by adding a service layer. In fact the service concept is at the core of both cloud computing and service oriented architecture. Cloud computing is a broader concept than utility computing and relates to the underlying architecture in which the services are designed [6]. It may be applied equally to utility computing services and data centres and both could contribute to energy saving of ICT usage.

3.2 The complexity of Operating Utility Computing

As a great deal of uncertainty still exists and also aiming to the deployment of utility computing further research is necessary for a deeper understanding and assessment of the environmental impacts considering systems boundaries conditions without neglecting essential implications. At the same time meeting environmental policy goals is required; and as such more accurate capturing interactions within such a complex system is needed. As operating a utility is also a complex issue, this holistic approach will encompass the several interrelated key aspects:

1. Intelligent transportation systems' impact on increasing transport performance and promoting a shift from the use of the private car to public transport
2. ICT based equipment's electricity monitoring and consumption in different sectors including the domestic and tertiary sector
3. Efficiency in electricity generation, distribution, monitoring and decrease the consumption using intelligent energy savings systems
4. ICT-supported the management of energy savings and allocation of incentives
5. Searching for new solutions based on advanced mathematics and/or biologically inspired methods (e.g. cuckoo search algorithm)
6. Using of a virtual utility to promote renewable energy and combined heat and power
7. ICT-supported systems for recovery and recycling of the waste in general and waste from electrical and electronic equipment in particular
8. Moving/Adopting IT utility services in the cloud and/or using only virtualisation technologies
9. Designing green data centres (servers, storage drivers, any telecoms equipment housed within the data centre) that should provide an alternative solution to reduce the power consumption
10. Efficient design and optimisation for green IT solutions including communication, networks and data storage
11. Including an impact assessment in early design stage of ICT products

4 Cloud Driven Environmentally Aware Digital Infrastructure

Several authors have analysed the environmental impact of running an ICT digital infrastructure due to electricity consumption (needed to run hardware e.g., workstations, servers, switches, backup drives, etc.) and cooling system (needed to reduce the heating generated by the hardware). ICT uses a great deal of energy and it is rising fast as follows [1]:

1. ICT equipment accounts for 10% of the UK's electricity consumption.
2. Non-domestic energy consumption from ICT equipment rose by 70% from 2000–2006, and is predicted to further grow 40% by 2020.
3. Data centres account for about a quarter of the ICT sector's emissions.

A cloud computing infrastructure for ICT as a utility is likely to substantially reduce all these costs, and the environmental impact alongside also reducing labour-related costs, as less people (e.g., technicians) than existing ICT infrastructures will be required to run a cloud-based ICT infrastructure.

In cloud computing, everything is defined and treated as a service such as SaaS (Software as a Service), PaaS (Platform as a Service) and IaaS (Infrastructure as a Service) [15], [18]. These services define a multi-layered infrastructure as shown in figure 3 and the related main services are defined as follows:

1. *Software as a Service* (SaaS), where applications are hosted and delivered online via a web browser offering traditional desktop functionality
2. *Platform as a Service* (PaaS), where the cloud provides the software platform for systems (as opposed to just software)
3. *Infrastructure as a Service* (IaaS), where a set of virtual computing resources, such as storage and computing capacity, are hosted in the cloud; customers deploy and run only their own applications for obtaining the needed services.

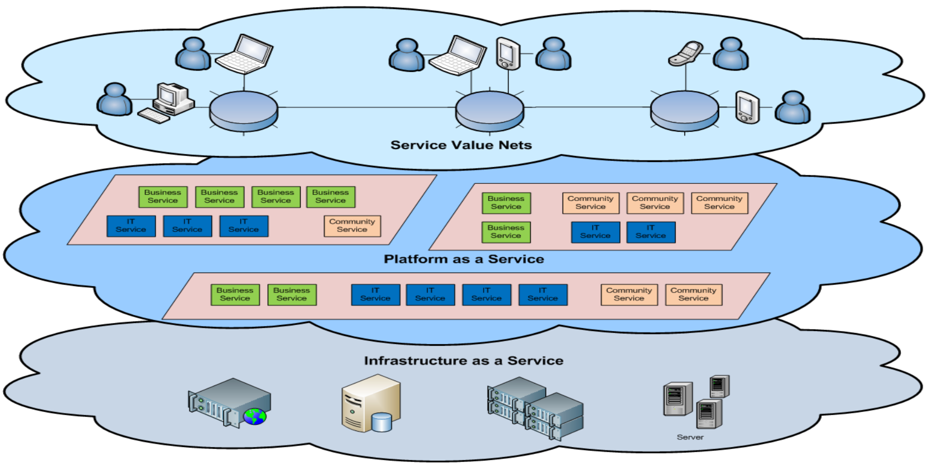

Fig. 3. The Cloud based Digital Infrastructure

At the infrastructure level, processing, storage, networks, and other fundamental computing resources are defined as standardized services over the network. Cloud providers' users can deploy and run operating systems and software for their underlying infrastructures. The middle layer, i.e. PaaS provides abstractions and services for developing, testing, deploying, hosting, and maintaining applications in an integrated development environment. The application layer provides a complete application set of SaaS. The advantage of the cloud based digital infrastructure is not just related to how much resources users can save by not buying and installing hardware and software and therefore using less power. Users of cloud computing are more likely to significantly reduce their carbon footprint. In the United Kingdom, for example, increasingly stringent regulations (such as the Carbon Reduction commitment and EU Energy Using Products Directive) are likely to put pressure on organisations such as the educational institutions to make ICT more environmentally sustainable [19]. In an environment where there is an increasing concern about organisations' carbon footprint and energy costs, virtualized services (such as those provided in a cloud based environment) are of very much interest [20]. Also data centers in the cloud could be environmental friendly storage, but concerns of data protection and privacy are also important.

5 Concluding Remarks

This approach is the basis for the definition of a systemic vision of green cloud based utility computing model. Despite the lack of quantitative evidence of the advantages of the systems approaches a balanced complete research agenda should include:

1. An holistic in-depth analysis of the impacts of ICT usage on the environmental sustainability and the definition of a roadmap through public consultation;
2. Effective inter-disciplinary systems research developing green sustainable ICT
3. Mechanisms for dealing with the complexity of operating utility computing, enhancing major benefits and minimising potential negative consequences particularly on the environment
4. Implementation solutions for utility computing using virtualisation for cloud based services and an elaborated digital infrastructure
5. Other key issues such as data privacy, and security and the need of a legal and regulatory standardised framework.

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