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Standardizing Sustainability Benefits of Cloud Computing for Non-Expert Decision-Makers

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ABSTRACT

Cloud computing is currently being provisioned and utilized by organisations in various and unstandardized approaches depending on the contract between the service provider and the end-user. The problem in this approach has been observed in the long-term cost, management overheads, and the environment sustainability associated with ICT usage. One method is to treat cloud computing services as a commodity via a metered billing approach, similarly to the way users pay for water, gas and electricity. This approach has shown a potential for sustainability and environmental benefits. These advantages have ranged from cost reductions, power optimisation, and simplifying in-house management processes. The objective of this paper is to examine the sustainability and environmental aspects of cloud computing services for non-expert users. The paper conducts an ICT energy consumption analysis and concludes a decision-making framework for the purpose of standardizing cloud computing sustainability aspects for non-expert decision-makers. The paper argues that certain cloud characteristics such as resource pooling, elasticity, multi-tenancy and service consolidating, can have a positive impact on any organisation with a medium or low-level ICT capacity in order to reduce energy consumption and gain future sustainability advantages.

KEYWORDS

Cloud Computing, Non-Expert, Sustainability, ICT

1. INTRODUCTION

Non-expert decision-makers have been observed to struggle when asked to evaluate cloud computing sustainability benefits or trade-offs before making decisions on whether to outsource core ICT components of their organisations into the cloud or not. This paper addresses this issue from a sustainability perspective by evaluating the current improper standardization of cloud computing models and features offered by top service providers.

At present, the audience of cloud computing is not limited to ICT specialists who operates in organisations with complex ICT work nature. Non-experts in almost all types of organisations are also benefiting today from different features of cloud computing. A basic definition of cloud computing for non-expert clients is the use of the

Internet for the tasks performed on computers. The Cloud here represents the Internet [1]. Non-experts can outsource in-house ICT components onto the cloud, or integrate newly added cloud components with existing in-house systems. The potential benefits to organisations from adopting cloud services were argued to illuminate capital investments for the ICT infrastructure in an organisation, reduce long-term expenses on ICT maintenance and upgrade, and limit the human interaction for provisioning and supporting ICT in the organisation. In addition, other benefits has been observed for being improperly standardised from the non-expert end-user perspective, whereas most research has been carried out on large datacentres and the service provider's perspective. Some of which is the sustainability and energy optimisation of cloud computing services. This paper addresses this benefit from a decision-making perspective for non-experts in accordance to the different cloud computing characteristics, hosting, and service delivery models.

The structure of this paper is divided as follows: Section 2 will introduce a brief background on the sustainability principles of cloud computing from the viewpoint of non-expert users. In Section 3, a literature review will be discussed briefly with reference to the current cloud computing energy-management services and market standards offered by academics and service providers. Section 4 will evaluate the main characteristics of cloud computing in accordance with the relevant environmental aspects. In Section 5, these aspects will be analysed through selected case studies in contrast to the cloud computing key architectural layers of Infrastructure, Platform, and Service. Following this, the paper will analyse results and evaluate the findings of the previous case studies in relation to the illustrated sustainability aspects. Section 6 will discuss the development of a cloud computing sustainability framework for non-expert decision-makers for the purpose of potentially overcoming the improper standardisation of environmental benefits and trade-offs, which accompanies different types of cloud computing features. At the end, conclusions and future works are listed.

2. BACKGROUND

Organisations and clients are using cloud computing services on a daily basis whether they realise it or not [2]. For example, internet email accounts, social networks, GPS locations, and numerous other forms of online data storage and sharing are constantly being accessed by millions of users worldwide. These services are supplied by ICT providers that own virtualized datacentres for end-users to access through the Internet. In general terms, cloud-computing is a ubiquitous platform which provides on-demand ICT services through either the public Internet, or other privately-managed and secure tunnelling networks like Virtual Private Networks (VPN) [3]. The Cloud concept came to life mainly because of the growing ICT requirements in almost each industry, which were not being fulfilled through previous models due to costly services and complex management procedures. Furthermore, another reason for the cloud features to take over conventional methods was due to the highly energy-consuming hardware, which is adopted in the traditional ICT deployments. This was more highlighted for large datacentres where a big number of servers and racks are adopted and using great amounts of energy including the cooling, ventilation, and other power-consuming associated tasks. Nevertheless, although organisations such as hospitals, shopping malls, government agencies and universities are not as ICT-dependant as the large datacentres in terms of the number of servers and other infrastructure, nevertheless, adopting cloud computing services can have impacts on the energy bill of those portfolios.

Several cloud computing scientists and organizations have identified different characteristics, service-delivery models, architectural types, and legal aspects of a system necessary to support cloud computing. According to the NIST definition of cloud computing concepts, five essential characteristics were necessary: On-Demand Self Service, Broad Network Access, Resource Pooling, Rapid Elasticity, and Measured Services [4]. In addition, experts from The Cloud Security Alliance have identified a sixth cloud characteristic and named it

Economy of Scale [5]. Furthermore, other client-cloud computing characteristics were widely discussed by many organizations, such as Multi Tenancy [6], which indicates the distributed manner of computing access and sharing of resources across the cloud. Cloud computing hosting models were divided into four interrelated models as follows:

- Public: Cloud providers offer a full range of computing services via online means, which enables organizations to outsource the entire ICT infrastructure into the cloud.

- Private: Organizations operate either on-site, exclusively managed, or via a third-party outsourced cloud, or a combination of both.

- Community: Multiple organizations with similar operational goals and security policies, share the same virtual ICT services and platform, which can be managed by one of the above, a third-party, or a combination of all.

- Hybrid: Often the most preferable cloud deployment method for end-users, as it ensures additional management flexibilities regarding security, risk elimination, information systems portability, and better standardization. The hybrid solution offers a mixture of various sub-components from previous deployment approaches. In particular, this model irrespectively combines the technical and nontechnical aspects from Private, Public and Community models [7].

Moreover, client-cloud computing potential benefits extend beyond obtaining cost reductions and management flexibility. On this note, multiple energy saving characteristics were pointed out by academics and service providers given that ICT virtualization can have a significant potential for eliminating plugged-in equipment, thus minimizing associated electricity consumption, space and management. The Green and sustainability characteristics of cloud computing are discussed and analysed in this paper from the perspective of non-expert decision-makers. A brief summary of those aspects are presented as follows: [8] [9]:

- Dynamic Provisioning: The ability to reduce unwanted cloud computing components through better matching of server capacity with actual clients' demand.

- Multi-Tenancy: The ability to normalize and flatten unmeasured peak loads by serving large numbers of clients on a shared hosting infrastructure.

- Server Utilization: The ability to operate servers at higher utilization rates via virtualization techniques.

- Datacentres Efficiency: The ability to use advanced datacentre features which reduce the overall power loss through improved methods of power conditioning, air cooling, and other methods.

3. LITERATURE REVIEW

This section will discuss the literature on existing sustainability approaches for organisations using cloud computing and virtual networking technologies, and current market solutions for cloud-based energy management in organisations with different sizes and work natures.

One of the major issues facing this planet today is pollution due to greenhouse gases. ICT-related pollution came to attention given the swift development of new technologies which led to the dumping of large amounts of unused and outdated hardware without a proper recycling strategies or waste management. The relevance of that to this paper is explained in what cloud-computing services can potentially benefit the environment if utilized properly in terms of eliminating outdated hardware through virtual methods. These fast advancements in both the industrial and digital fields have raised many concerns regarding different environmental aspects such as greenhouse gas emissions, waste management, the output of raw material, and the availability and consumption of energy which is especially witnessed in third world countries.

Moreover, carbon monoxide's high rates were observed by experts to reach unprecedented levels, especially in developed urban cities where almost half of the world's population resides [10]. These highly developed cities can be currently portrayed as the battlefield ground between different organizations which include the environmental side on one hand that strives for sustainability, and the winning side which only seeks economic prosperity [11]. With respect to the disappointing history of achieving ICT sustainability despite the massive amount of literature published on this subject, not much was offered in terms of how to effectively balance both economic growth and sustainability in an ICT infrastructure strategy.

One of the major potential benefits from implementing fully, or partially on-demand cloud-computing solutions in organisations, is the ability to acquire an easily maintainable energy saving, and self-healing cable-free infrastructure [12]. Whilst the logic behind this statement arises due to the properties of virtualized techniques achieved through online dependent cloud-computing concepts, the general statement assumes that accessing and controlling the entire organisation's internal systems requires nothing more than a simple, reliable, and secure internet connection. These tasks outsource using such an approach correspond with internal functions, including IT systems, HVAC equipment, sensors, elevators, lighting control, CCTV, fire alarms, and other implemented building devices.

Following this through easily attainable online access by a secure WIFI network as an example, a large-scale of permission management, administration, and heavy daily support can to a certain degree be outsourced to external datacentres owned and operated by cloud providers [13]. In consequence, a high number of connected organisations can be managed simultaneously using the same ICT infrastructure. As a result, several sustainability objectives can be considered achieved from such migration procedures, as earlier attempts to acquire a cable-free virtualized building solution were unsuccessful due to complex networking hardware and wiring infrastructure.

In relation to energy efficient ICTs for smart applications, whether related to organisations in buildings, transportation, agriculture or any other smart principle; it can be acknowledged from previous published work that cloud-computing techniques have not been standardized and applied as a fully operating IT platform. The reasons behind this are due to performance, administration, and security vulnerabilities. Although similar topics have been the target of numerous computer science studies concerning virtual information benefits for companies' IT solutions, only a few papers have discussed the energy efficient advantages from cloud-computing utilization as will be listed next. In addition, it can be concluded from previous literature that cloud-computing benefits with regard to sustainable management and decision-making approaches are, in most cases, presented as a secondary topic in a broader energy consumption study [14] [15] [16].

According to a 2009 study by the British Computer Society and Oxford University Press, energy efficient cloud-computing has examined several Low carbon footprint approaches for IT datacentres and communication services [17]. For the primary aim of reducing Green House Gas Emissions (GHG) from computation and the physical space occupied by associated hardware, the paper significantly portrays the cloud approach as an inherently power saving technology that has recently attracted the large-scale of attention of non-expert managers. However, it has been pointed out that despite the fact that most literature has focused on hardware aspects in relation to usage, optimization, and energy efficient performance, the information and communication services for potential Green solutions has not been fully implemented as an ICT infrastructure. In particular, cloud-computing solutions were mainly deemed at that time inapplicable for potential power consumption reduction.

Moreover, the study discussed various benefits to be gained from implementing an IT solution based on cloud concepts. These services, which to a considerable extent, are categorized Green in different operational tasks, performance, and energy-aware aspects, are fundamentally concerned with dumping heavy computational workload on an online virtually-managed system. In theory, this workload is only required either infrequently, or on a scheduled basis. For example, a certain datacentre processing function might be needed for only 30 minutes on a Sunday night, such as crunching a large number of data as part of a weekly backup. Although this particular task requires a hundred parallel servers, the normal building operation only requires 50 servers to operate on a normal workday basis.

The paper has also analysed Amazon's cloud-computing monthly costs regarding a datacentre's energy distribution over a 3-year period [18]. Furthermore, the study argued that an estimation of 30% savings can be obtained from unnecessary cooling power. In addition, 20% of energy emitted from networking infrastructure in a sizable building could also be dispensed with [19]. Regarding the potential benefits of cloud-computing for the environment, a 2008 study by the Accenture has argued that energy consumption from networked-based servers alone can be reduced by 20% from using cloud services [20]. In addition, HP stated that savings from cloud-computing deployments can reach up to 30% with regard to the energy spent on cooling for heavy-duty hardware. Furthermore, it was estimated by the same study that the carbon exhaust of these equipment is currently reaching around 70% of the datacentre's total power exhaust.

The main conclusions were centred on achieving virtualized, energy efficient solutions while providing insights on how to best manage the approach in large-scale infrastructures. These environments have a high demand for information and communication services as well as various other nontechnical requirements, which can also be integrated onto a single virtualized platform [21].

Microsoft published a report on cloud-computing smart applications, which discussed potential possibilities for cloud approaches to achieve power efficient resource management [22]. According to a 2011 Microsoft Corporation report on making organisations smart, control over the cloud has recently been one of the centrally debated topics. Further, smart transportation, and a new generation of grid systems were both considered essential platforms for achieving sustainability.

Case studies concluded that accurate decisions to enhance energy performance and management in Smart Buildings could not be effectively executed in real-time circumstances, as it was simply impossible to make sense of events, reports, and data analytics captured from IP systems. This was argued as one of the problems cloud-computing can solve via the Infrastructure as a Service layer (IaaS). The study argued that these recently innovated cloud approaches are transforming the way energy consumption, in both buildings, and cities will occur in the long-term. Although full IT transparency is being offered for networking and processing infrastructure, contributions from several Microsoft partners like Hitachi, Stanford and California University, are comprehensively examining methods to enhance current models on Smart Building energy management. For instance, the previous model suggests connecting a network of organisations into a Smart Grid, which to some extent can potentially be deployed across the world.

4. MARKET SOLUTIONS FOR CLOUD-BASED ENERGY MANAGEMENT

According to a revenue chart created by the Pike study, the market of energy systems for Smart building management has had a growing and almost consistent rate of revenues since the introduction of cloud-based services. For example, while revenues have gone as far as $ 2 billion in 2011, it has been estimated that by 2020 a return profit of $ 6 billion will occur from using the Panoptix service by Smart Buildings in the US alone [23].

According to Fujitsu, a smart energy management service referred to as Enetune was set to be launched in June 2013 as part of an energy optimization process for businesses and organisations located over multiple locations [24]. This service will employ the online Cloud as a data capturing, storing, and processing platform from different energy consuming sources [25]. Cloud-based services arrive with a bill at the end of each month. For example, the Enetune EMS service costs about 400 US dollars per project (location) on a monthly basis. This is excluding support, upgrades or any other bespoke features.

It was pointed out by the development manager at Open General that the migration process from conventional web-enabled technologies in a building energy management system, into a transparent cloud-based solution, is considered essential to data integration methods within organisations [26]. In particular, with the employment of open communication protocols such as BACnet, Zig-Bee, and Mod-Bus, two levels within the system architecture has been identified with regard to data integration: Software level and the Controller level.

According to an article by Automated Buildings Enterprise, the current market of cloud energy management for organisations is leaning strongly towards a Hybrid interconnected approach [27]. This connection is expected to take place with several related industries such as Smart Grids and others. An example of such services to support this application is the use of Virtual Real-time Information Systems (VRIS) [28] [29].

A research at Microsoft has carried out a cloud-computing energy performance study with respect to selected applications from the ICT organization such as Word, Excel and Outlook exchange [30]. Whereby the deployment of these tools is considered almost a given in each Smart Building ICT environment, the main objective of the study was to highlight greenhouse gas emissions from utilizing a Microsoft cloud-based alternative.

Other studies have identified the cloud-computing energy optimization factor via mobile platforms. This was particularly discussed in a study by Purdue University where the main objective was focused on enhancing computing capabilities and applications across mobile devices [31]. The ultimate solution was to ensure maximum battery life for ad-hoc ICT systems. Although cloud utilization was debated as a potential solution for a low-power ICT lifecycle, multiple challenges were addressed.

In reference to power consolidation via cloud approaches, another study was deemed significant to this research given multiple Smart Buildings' ICT services [32]. The paper addressed the mutual liaisons between ICT utilization on one hand, and associated energy consumption on the other while taking into account execution performance obtained from strengthened workloads. The main focus was highlighting complexities in achieving energy consideration by identifying both performance barriers and benefits gained from energy consolidation across different smart environments where a certain degree of system integration is accomplished.

5. SUSTAINABLY ASPECTS OF CLOUD COMPUTING

The dynamic scaling ability offered by on-demand cloud services provides the opportunity for energy saving in organisations, this is now discussed. It was argued that ICT investments are the most influential factor for attaining 'Green', low carbon organisations [33], also, numerous projects have recently been carried out on adopting emerging ICT solutions for contributions to energy saving [34] [35]. For instance, EU Commission standards, initiated in 2009, investigated the significance of in-depth relationships between ICTs' technical administration, and energy-intensive industries such as Smart Buildings and Transportation.

According to the Accenture Group and in response to intensive virtualization and economy of scale techniques applied by cloud datacentres, cloud-computing solutions have the ability to reduce a company's carbon emissions by approximately 30% per IT user [36]. This was argued as being a result of outsourcing applications, networking bandwidth, and processing units into cloud-hosted datacentres. This indicated that some ICT components deployed in a non-virtual manner are responsible for energy consumption in terms of different portfolio sizes and workload. The following will present cloud-computing contribution to power usage minimization with reference to the previous literature analysis. This is argued in accordance with key cloud management attributes discussed earlier.

In a normal organisations in a building environment, users (e.g. people or IP devises) access the internet through either a local area network (LAN) cable (e.g. RJ 45), or via a direct wireless connection. Then, a cloud service request, which follows IaaS, PaaS, or SaaS, is sent as IP packets from the internal on-premises router to the internet provider's main router, to eventually reach the cloud service provider's gateway router. These requests are then subsequently dispatched to a shared pool of distributed virtual machines (VMs), which host a diverse scope of ICT resources, covering software applications, development platforms, processors, and networking bandwidth. Each step of the previous process consumes a certain amount of energy. Other tasks/services that are not directly involved in the cloud service delivery process (e.g. cooling, lighting, and electrical equipment needed to support the ICT lifecycle in Smart Buildings) were argued to consume the largest part of energy [37].

Research found during the Literature Review chapter has particularly highlighted four key areas of cloud characteristics by the Accenture group, which demonstrated positive impacts on reducing greenhouse gas emissions and refining ICT energy usage in organisations. These aspects have covered:

- Dynamic provisioning
- Multi-tenancy
- Virtualization
- Server capacity utilization
- Cloud provider's large-scale datacentres

Other sub-factors were identified in the overall ICT energy consumption process in organisations, in which cloud computing has a strong potential to optimize (Table 1).

To date, cloud experts claim that there is not a clear consensus towards classifying cloud-computing as a Green ICT [39]. Generally, management awareness was considered arguably misperceived towards cost minimization on one hand, and reducing ICT electricity usage on the other. While many features in organisations aim to automate as much end-user tasks as possible, in-house ICT infrastructure is mostly over-implemented as deliveries and capacity exceed what is actually needed, through the use of costly systems. This was termed in the conservative and traditional service methodology as Over Provisioning. This approach would result in minimizing energy efficiency and maximizing carbon savings, as this indicates that multiple versions of each system or networking process, is replicated, installed, and supported separately on each site.

In most cases when unpredictable heavy user access occurs, it is very difficult to predict the amount of bandwidth required to install a specific system. Non-expert decision-makers might adopt several frameworks for Green ICT operation; however, another crucial aspect must be taken into consideration. This highlights analysing resource minimization of internally hosted alternatives. Accordingly, cloud providers' energy efficient datacentres are mostly run next to massive renewable energy sites in order to maximize energy usage in the best way possible [40]. Organisations can rely on these heavily-burdened structures for obtaining resource-efficient ICT systems with minimum on-site equipment installed. However, this should be performed prior to taking into consideration all energy consuming attributes within the ICT environment. These attributes were defined by several academics throughout different frameworks via ICT power-usage parameters as [41]:

- COP (Coefficient of Performance) average
- The Carbon intensity of the electricity being used by each ICT component (kg/kWh)
- Electricity prices per ICT component
- Networking (next-hop) cost per GB, for data transfer (up/download)
- CPU uptime, downtime, quantity, frequency ratio, and power required

Cloud computing has a significant potential for eliminating plugged-in equipment, thus, minimizing associated electricity consumption, space, and management effort. More, this was assumed to reinforce Green utilization for Smart Building ICT applications. In addition, the fact that in most cloud hosting cases energy is being displaced from onsite to offsite, this displacement only saves energy if these processes can be run more efficiently due to economy of scale (e.g. large datacentres) [42]. These datacentres could be situated in geographically favourable locations such as cooler climates, which will have lower cooling loads than buildings located elsewhere which are using those off site servers.

In concern, multiple energy efficient aspects were concluded in response to previously discussed cloud characteristics as clarified next.

• Enabling Resource Virtualization

Regardless of the deployment method, the core concept behind cloud-computing is the ability to run several operating systems on one machine. Therefore, adopting virtual machines with relatively similar capabilities can be acquired either on, or off-premises within a single or multi-branched ICT environments. With that in mind, the e-waste footprint of each ICT element such as servers with high CPU power can be substituted by VMs, thus, reducing electricity spending and energy of physical plugged-in units.

• Strengthening Consolidation

Although virtualization is considered the primary cloud energy-efficient aspect, a crucial reliance on software automation for scaling up/down as workload demands, forms a key benefit behind virtual ICT implementation. This criterion allows non-expert Smart Building decision-makers to fully utilize rented cloud resources in contrast to resource ratios via conservative physical ICT methods. The conventional approach was noted as more costly and power consuming in reference to unhandled high rates of server utilization, which can be minimized through virtualization and a solid backup of software automation.

• Enabling Energy-Efficient Behaviour

The pay-as-needed billing concept of cloud-computing has a significant impact on energy end-user behaviour for enhancing lifecycle administration and service oriented expenditures. More, while Smart Buildings' heavy ICT dependence mostly includes the utilization of plugged-in, off-site, and third party managed infrastructure, this is accomplished - in cloud terms – following an as-needed approach. Each unwanted ICT element will simultaneously be switched off, and these resources are then pushed back into the shared pool as previously explained in the cloud characteristics section.

• Applying Multi-branched Demand Patterns

In relation to a multi-branched set of Smart Buildings such as Banks, Hotels, or Hospitals, operating on a single networking platform, the multi-tenancy attribute of cloud-computing is considered a major energy saving aspect for several reasons in accordance with each cloud deployment model as follows:

- Public clouds mobility standards allow differently located users to access ICT services and applications from anywhere via the Internet, while taking into account several security, reliability, and data integrity considerations. This saves energy in Smart Buildings because these users are relying more on privately owned end-systems from off-premises locations, which takes the load off the organization's ICT infrastructure.

- Private clouds, which are installed on one site such as the main headquarters of the organization, can act as a cloud provider datacentre for other Smart Building branches. These are able to access, utilize, and release ICT resources by following similar public cloud techniques.

- Hybrid clouds, whether deployed on or off-premises have a significant role in reinforcing both the security and performance of previous approaches as discussed earlier in the deployment models analysis.

Previous points indicate that each location with a certain workload peak rate, have a strong potential for saving energy. For instance, peak rates for networking, processing, or application access are widely reduced when distributed between multiple end-users via shared demand patters. Although less physical infrastructure is required as a result, the economy-of-scale aspect of cloud-computing plays a considerable role in maximizing energy efficiency and resource troughs.

6. CASE STUDY ANALYSIS

This paper interviewed a senior manager at [a popular ICT provider] in the UK. This interview has followed a semi-structured approach and covered potential environmental and sustainability benefits or trade-offs of this company's client records from the perspective of non-expert decision-makers.

It was first confirmed by the interviewee that SaaS services are currently the most popular among the majority of the provider's clients. The Hybrid Hosting was identified by the interviewee as the most popular deployment model across the current clients. The following figure shows how cloud services have almost achieved the ICT demand level of end-users, while the classic capacity line is fixed and does not always correspond with the ICT demand of end-users. As a result, end-users will end-up with either (Figure 1):

- Over Capacity: This will occur when organizations use owned conventional ICTs that have more capacity than required in real-life. As a result, these users will be forced to continue managing and paying for system runtime and maintenance of unneeded ICT infrastructure.

- Under Capacity: This will occur when organizations use their owned conventional ICTs that have less capacity than required in real-life. As a result, these users will be forced to fully purchase new systems to meet this demand, and provide support for this new infrastructure, which is only needed for a short period of time.

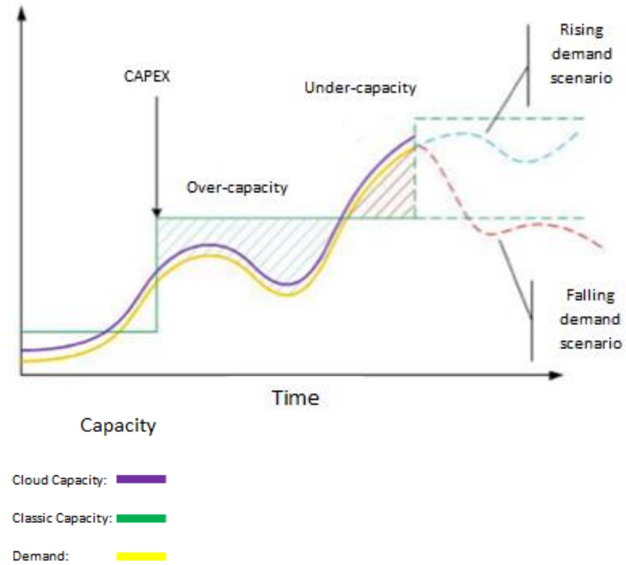

Figure 1. Capacity comparison of Cloud vs. Classic Demand

This According to the provider's client records which were provided exclusively to this paper, consumers with unstable ICT demands are complaining from the rising cost of their existing in-house systems. The Over Capacity is observed more in big organizations where unexploited resources are purchased, which leads to additional expenses on support and upgrade. However, the Under Capacity aspect is observed more in small organizations where less ICT demand is usually required in most applications.

In relation to the energy-efficient cloud-computing factor, it can be concluded from the interview that big provider names in the ICT industry are focused on service delivery in terms of support, availability, and customer satisfaction, rather than empowering organisations with energy-efficient features of cloud applications. This conclusion came primarily as a result of service requesters' demands towards eliminating in-house ICT maintenance, upgrades concerns, and staff salaries. It was observed by this paper that the majority of clients over the past 5 years are not particularly interested in the energy-efficient benefits gained from cloud services. Their main interest is obtaining cost reductions and decreasing time-consuming management efforts. The interviewee explained this by stating that obtaining considerable energy cuts from cloud computing is still a debatable argument depending on multiple

Table 1. Energy consuming Elements against Cloud-Computing Contribution for Organisations

Energy consuming ICT Elements	Cloud-Computing Contribution	Example
Core Applications	Eliminating extensive CPU power	Internally installed, long-running software consume a considerable amount of CPU power (e.g. CRM tools for banks, security monitoring tools for shopping malls, etc.). Although this is not usually a concern during the development of these applications, electricity consumption can be reduced through outsourcing core applications through utilizing SaaS resources, which are virtually run over distributed machines at the cloud provider's infrastructure.
PCs & Servers' Response Time	Reducing end-user response time by relying on distributed VMs instead of high performance on-premises servers	Non-expert managers in different types of organizations have a tricky task of weighing cloud-computing QoS and energy saving features on one hand, with branching limitations on the other. For example, it is well known that any physical server would perform, to a large extent, better than a virtual substitute [38]. However, enhancing response time is nonetheless a major energy saving attribute, as cloud providers mostly employ a large number of VMs assigned over globally located datacentres, hence, ensuring reliability via data replication, rapid provisioning, and availability rates.
Networking Hierarchy Systems	Minimizing capacity bandwidth from no-more-necessary internal networking devices (e.g. topology design, wired networking awareness)	Utilizing cloud solutions could relatively increase networking processes regarding number of hops between source and destination. However, employing a dynamically scalable infrastructure as a service IaaS, will only consume energy on the basis of delivering packets to the in-house router according to peak workloads. This is done in Smart Building networking systems, which are mostly structured to deal with worst case scenario such as throttle-neck periods. As a result, this can eliminate internal connection complexities as opposed to implementing conventional on-premises datacentres that require power-burdened networking devices (e.g. switches, cables, signal power points, hubs, conditioning equipment, etc.).

ICT attributes related to the specific organisation involved.

7. SUMMARY OF FINDINGS

One of the key examples presented by the interviewee was the VisitBritain agency, where the cloud sustainability factor has played a significant role in forming the client's ICT strategy. In this example, a large amount of hardware, and networking infrastructure was required to support a heavy communication processes and ICT capacity peaks.

This demand was only required for the 2012 London Olympic games, which only cover one month of uptime ICT utilization. Therefore, cloud-computing features were a great solution for this scenario, avoiding having both over capacity and under capacity at the same time. Furthermore, cloud-computing sustainable techniques played a significant role in that respect, where ICT virtualization, migration, and support, provided large scale virtual machines, server components, networking bandwidth, and 24/7 contingency maintenance of an entirely outsourced infrastructure.

In terms of the feasibility to outsource and host an entire building's networking infrastructure on a cloud platform, end-users will only be required to use thin-client Graphical User Interfaces (GUIs) as an on-site ICT infrastructure. Examples of these GUIs are screens with ad-hoc ports Ethernet access and minimum buffering power such as IBM pure-systems, Google ChromeBox Cloud-based PCs, which are an optimized private cloud with a self-service user interface.

The paper simulated costs and potential energy savings in a major [higher education facility] in the UK, which is currently using conventional ICT hosting methods. Following a semi-structured interview with the university's Information Director, this paper gathered the following date. The university employs 25 ICT personnel in-house, and the total cost assigned to the ICT infrastructure per year is £0.5 million. This was divided as follows:

- £ 100,000 for Information Systems upgrade
- £ 250,000 for Networking and Communication Systems upgrade
- £ 100,000 for Hardware Maintenance (e.g. core networks, remote monitoring, etc) (20% of the total budget each year)
- £ 50,000 for Software support from various vendors (excluding fixed contract costs)

This paper used the tool: SBCE, which has been developed as part of a PhD project at Heriot-Watt University in 2016. The tool offers dynamic and elastic cost estimation, simulation and management consultancy features in addition to energy saving calculations of the ICT infrastructure for organisations. After selecting the substituted ICT components that were estimated if cloud computing was adopted in contrast to the current conventional methods, the following savings were calculated which compares between thin and thick clients, and the total cost of the ICT infrastructure.

Estimated Total Cost for the first year cloud-computing simulation: Deployment costs (£ 73,322.40) + Support costs (£ 22,889.22) = £96,211.62

Estimated Total Cost for the three years cloud-computing simulation: Deployment costs (£ 220,106.44) + Support costs (£ 68,707.82) = £288,814.26

It can be concluded that applying a cloud solution seems cheaper than the on-going multi-vendor, in-house solution. This was demonstrated from the £0.5 million pounds spent by the university on the ICT infrastructure per year, in contrast to the £96,211.62 required for the first year from applying the cloud alternative. The previous results are excluding any additional elasticity service demand patters, or any fixed service contracts with specific vendors such as Blackboard, and others, which costs Heriot-Watt University around £ 50,000 per year as explained earlier.

The university acquires about 5,000 computers covering school labs and staff offices. These in addition to the main library are administered privately by the in-house ICT support team. In that context, this study previously proposed the purchase and utilization of light-weight thin-clients, instead of the currently utilized thick-client devices. The former will soon become obsolete resulting in thick-client hardware being dumped and replaced on a regular basis. Therefore, expenses related to purchasing, upgrading, managing, and licensing, are enormous as the university's DIS has acknowledged in the interview earlier. In addition, with regard to hardware acquisition and associated power consumption for the entire infrastructure, the Green aspect of operating in an environmentally friendly manner can be drastically improved from employing thin-client equipment.

For instance, Google and Samsung offer ChromBox, a light weight PC that only consumes 8-15 watts instead of the 250 watts per each regular thick-client device. As a result, end-user device costs can reach around £ 269 instead of a £ 600 average for an HP desktop computer. With accordance to the higher education case study, the number of watts approximately consumed by end-user PCs only can be measured approximately as follows (Table 2).

Table 2. Watts approximately consumed by end-user PCs: Thick-client vs. Thin-client

Following the existing thick-client approach:	*5,000 PCs: each PC consumes 250 watts ↔ 250 x 5,000 = 1.25MW (Total Consumption)* *5,000 PCs: each PC costs £ 600 ↔ 600 x 5,000 = £ 3,000,000 (Total PC Infrastructure Cost)*
Following the potential thin-client approach:	*5,000 thin PCs: each PC consumes 12 watts ↔ 12 x 5,000 = 60,000 watts (Total Consumption)* *5,000 PCs: each thin PC costs £ 269 ↔ 269 x 5,000 = £ 1,345,000 (Total PC Infrastructure Cost)*

By default, any thick-client device will exclude costs related to any operating system licenses, anti-virus protection, and other required software, given that devices like ChromeBox are online-based, self-healing with automatic built-in system upgrade. Moreover, other desktop computers were also classified under the thin-client category. These have also been argued to optimize energy usage, minimize hardware possession, and ensure efficient remote utilization of resources given that the operating system is already hosted on the manufacturer's cloud environment [43]. Some examples of today's ICT market, this light-weight hardware can range from the HP MultiSeat PC, to the Wyse computer by Dell, in addition to other networking storage systems such as Sun MicroSystems, KronosSystem, and ReadyNAS by NetGear.

8. CONCLUSION AND FUTURE WORK

The objective of this paper is to standardize the sustainability aspects of cloud computing from the perspective of non-expert decision-makers. The paper introduced a brief background on the sustainability principles of cloud computing from the viewpoint of non-expert users. Following that, a literature review was discussed briefly with reference to the current cloud computing energy-management services and market standards offered by academics and service providers. Furthermore, the main characteristics of cloud computing in accordance with the relevant environmental aspects were discussed and analysed through selected case studies in contrast to the cloud computing key architectural layers of Infrastructure, Platform, and Service. The paper then analysed results and evaluate the findings of the previous case studies in relation to the illustrated sustainability aspects.

As discussed, studies such as the UN Habitat indicated that developed cities with high population such as London and Beijing, are accountable for nearly 85% of greenhouse gas emissions [44]. According to other previously reviewed studies, this number classified these cities, in carbon terms, as unsuitable places to live in the future. It was also stated that organisations in buildings are responsible for around 45% of energy consumption in Europe alone. In particular, ICT in a normal building with medium-capacity datacentres is currently responsible for over 10% of the total cost of this structure. Furthermore, the overall global CPU power and storage capacity was observed to double every 18 months, and the global ICT consumption growth was noticed to rise from 123 billion kWh in 2005, to 246 billion kWh in 2010. This reflected a 2% increase of the worldwide CO2 emissions. As a result, it was estimated that a set of server racks, which include around a thousand servers, would currently cost around $ 4.5 million, mainly due to its power consumption in a normal capacity datacentre. Cloud-computing was introduced to help mitigate this issue, not only from ease-of-management and economical perspectives, but also in relation to various associated environmental factors. This was argued to have a strong potential to minimize software and hardware physical acquisition and usage in different types of organisations.

The main conclusions can be summarized as follows:

- An observation was made that cloud experts currently claim that there is not a clear consensus towards classifying cloud computing as a Green ICT.

- In almost organisations, Servers occupy the biggest percentage in cost and energy consumption as opposed to all other ICT components and associated attributes. In addition, 42% of the power consumption of an ICT-burdened organisation is designated to the cooling infrastructure.

- The main conclusion argued that for a Green installation in a heavily ICT dependent organization, adopting cloud-computing was in most of the client cases -from top service providers- more cost efficient in terms of hardware, datacentre costs, and management. In the long-term, in some cases the savings got lower when a client moves from a legacy environment into a cloud one due to extra costs such as support expenses, and non-planned hardware upgrade.

- With regard to the higher education facility cost and energy spend simulation, cloud-computing was observed to be cheaper and more energy efficient than the conventional existing approach for a 3-year deployment.

Future work is suggested to highlight the energy use of specific industries with accordance to ICT, and evaluate the potential energy reductions from adopting cloud computing services. This would offer a better understanding of each industry individually, hence, the research would assist non-expert decision-makers in identifying the trade-offs, benefits, and areas of concern that are only specific to their organisations' work nature, operational objectives, and other administrative attributes such as size, employees, and budgets.

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