Green Cloud Computing: An Experimental Validation

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Abstract. Cloud configurations can be computational environment with interesting cost efficiency for several organizations sizes. However, the indiscriminate action of buying servers and network devices may not represent a correspondent performance number. In the academic and commercial literature, some researches highlight that these environments are idle for long periods. Therefore, energy management is an essential approach in any organization, because energy bills can causes remarkable negative impacts to these organizations in term of costs. In this paper, we present a research work that is characterized by an analysis of energy consumption in a private cloud computing environment, considering both computational resources and network devices. This study was motivated by a real case of a large organization. Therefore, the first part of the study we considered empirical experiments. In a second moment we used the GreenCloud simulator which was utilized to foresee some different configurations. The research reached a successful and differentiated goal in presenting key issues from computational resources and network, related to the energy consumption for real private cloud.

1. Introduction
Cloud configurations are steadily increasing their energy consumption due to the large number of clusters and multi-clusters environments. On the other hand, it is estimated that the waste of energy to support these cloud configurations are much higher than costs to acquire these configurations.

An energy consumption policy is an essential approach to be considered in any organization. The lack of knowledge on how to adopt standards, and also metrics, leads many data centers managers to a puzzle on how to measure energy efficiency from their environments. In other words, in many cases, managers do not know how to calculate their configurations energy efficiency.

The importance of this research is exactly in this key issue for any organization that has, or utilizes, a cloud configuration. The contribution reflected a real case study from a large corporation. This study case represents a private cloud scenario, where not only computational resource facilities are taken in
consideration, but, also, costs related to the transmission from network devices. Therefore, the differential contribution of this article is to provide an energy consumption number that considers not only the computation, but, also, elements (e.g. links and devices) related to the communication.

In order to use standard metrics, we adopt concepts published in researches found in [1] and [2]. These researches take into consideration costs related to bit transmission from different type of users in a cloud configuration, and then indicate an appropriated configuration.

Therefore, our proposal considering those standard metrics is to evaluate the efficiency of a data center configuration utilized as a private cloud provider. The evaluation adopted in this paper comprised two phases. The first step was characterized by an empirical measurement and the calculation of energy consumption. In the second part of our research it was evaluated power consumption through the GreenCloud simulator. This procedure can appear in a reverse order, but the idea was to learn how to calculate the energy consumption and then scale the configuration size to a large environment.

The article is organized as follows. In second section some basic concepts related to green IT, characterization of devices energy consumption and energy efficiency are presented. Consumption metrics, calculus model and energy consumption analysis are illustrated in the third section. The fourth section shows the cloud configuration study case scenario, describing characteristics referring to the computational central core and corporate configuration. Experimental results and presented and discussed in the fifth section. Finally, in the sixth section we present our conclusions and research future directions.

2. Concepts Context
Concepts related to green cloud, energy efficiency and network devices utilized along this paper are explained in this section. Usually, those concepts can be employed broadly in several different contexts. Therefore, the goal of this section is to provide a primary idea on how these concepts are used in cloud computing scenarios.

2.1. Green Cloud
The recent trend on the intensive utilization of cloud configurations, as the paradigm to delivery services and execution of applications in a global fashion, brings also together a considerable increase on energy demand to support these data centre configurations.

The Gartner group [3] indicates that the data centres energy consumption reaches around 10% of operation costs of total costs. These costs are also known as Operational Expenditure (OPEX). Some studies (e.g. [1]) indicate that this energy consumption number can reach around 50% in years to come.

A study presented by the Environmental Protection Agency (EPA) [4] shows that the American data centres have energy consumption equal to 4.5 billion of kWh per year. This number represents 1.5% of energy consumption of the country. The research also indicates that the energy consumption double during the period from 2000 and 2006. Thus, it is expected that the new model of business based on cloud computing could lead the energy consumption to higher levels.

Heating is other important element which should be taken into the account of energy consumption in a cloud configuration, where it is related to infrastructure temperature maintained, because of machines of the environment. On other words, it is reported in commercial literature that the heating created by the machines from a cloud configuration can represent a cost between 2 and 5 million, considering a standard data centre. Therefore, as it is shown in [3], an optimized infrastructure can reduce costs related to the OPEX.

2.2. Energy Efficiency
As it is presented in [5] and [6], energy efficiency is traditionally a vital element to any kind of industry. The new type of industry in this scenario is the IT companies, because the energy consumption is been shown as relevant cost in their scope [12].

Following [7], for the cloud computing viewpoint the energy efficiency can be understood as:

- A set of computational resources and links organized in a way that the input energy can be efficiently transformed in calculus, or data transfer, to support users’ requirements.

As pointed out in [8], usually, when the energy efficiency parameter is mentioned in a document, the computational power from servers and how they generate heating are main concerns. In a second moment, the parcel of cooling is the targeting of the concern. The amount of energy consumption has several factors, with a variety of reasons, but the low utilization of computational configurations is indicated as the most important factor.

2.3. Network Devices
Several studies (examples are [2] and [9]) indicate the low use of computational resources for long periods. It is estimated that these numbers can reach around 70% of idleness against 30% of full resource capacity use.

Therefore, the result is a large number of computational resources with a high inefficiency levels to provide service. Thus, this fact generates waste of energy, heating dissipation and the power necessary for cooling to those unused resources.

It is important to mention that several researches do not observe the power consumption from network devices. Nowadays, these elements are becoming more and more essentials, and be taken into consideration, because clustered configurations are the main computational core. In addition, several links exist with different complexities.

The research presented in [10], network devices (e.g. switches, routers and communication links) are regarded as a 15% of power consumption from data centres.

Similar to the computational resources, such as servers and terminals, network devices can also have their voltage and frequency reduced, under certain amount of demand, targeting to decrease the energy consumption.

3. Metrics, Calculus Model and Energy Consumption Analysis
In this section, it is presented some metrics, the calculus model and how is the process to verify and analyse the energy consumption, adopted in this research work.

3.1. Green Cloud
The general proposal of energy consumption metrics is to provide a global view of the infrastructure energy efficiency, especially, considering the consumption of element IT.

The era of cloud configurations has created a high demand for costs control from energy. This fact can be explained because data centres are growing in a form not known before. In addition, a lack of an official standard, or a the facto one, accepted by the community creates inconsistencies in practices to measure energy consumption.

Manufacturers, usually, have their own practice to measure metrics of consumption. Therefore, it is essential a recommendation to those organizations, that are seeking for a standard procedure to measure and analyse energy consumption from their IT infrastructure. In other words, providing a clear and objective method on how to measure and analyse energy consumption from a cloud configuration.

In this research work, we consider the power usage effectiveness and data centre infrastructure efficiency as metrics to measure cloud environments energy consumption. These two metrics are being accepted as reasonable parameters related to the data centres energy consumption.
3.1.1. **PUE.** The power usage effectiveness (PUE) is a parameter that seeks for efficiency utilization of the energy provided to a data center. This metric is recommended to characterize and provide information related to energy from the entire data center infrastructure [16].

PUE utilizes the energy consumption as a source for the calculus. PUE is characterized by a comparison between the total energy from a data center infrastructure and the IT energy parcel, thus:

\[
PUE = \frac{\text{(Total data centre energy consumption)}}{\text{(IT energy consumption)}}
\]

3.1.2. **DCIE.** The data center infrastructure efficiency (DCIE) is characterized by the inverse calculus of the PUE. The DCIE goal is a complement to the PUE metric, because represents the efficiency percentage from the data center infrastructure.

\[
\text{DCIE} = \frac{\text{(IT energy consumption)}}{\text{(Total data centre energy consumption)}}
\]

3.2. **Calculus Model**

The calculus model considered in this paper is based on the proposal presented in [2]. This proposal takes into consideration the bit energy as fundamental measure of consumption. Important to remember that, into a cloud configuration, the energy efficiency can be translated to a number that represents the consumption energy spent to execute a set of data bits, which were used through the cloud environment.

The \( E \) energy, following [2], can be expressed as:

\[
E_c = 3 \times 3 x \left( \frac{P_{\text{les}}}{C_{\text{les}}} + \frac{3 P_{\text{es}}}{C_{\text{es}}} + \frac{P_g}{C_g} \right) \quad (1)
\]

Where, \( P_{\text{les}} \), \( P_{\text{es}} \), e \( P_g \) correspond, respectively, to the energy consumption related small Ethernet switches, switches and routers.

On the other hand, the parameters \( C_{\text{les}} \), \( C_{\text{es}} \) e \( C_g \) mean all the equipment capacity in bits per second.

The first 3 factor from equation 1 is related to redundancy energy (this number is assumed as equal to 2). The calculus also takes into consideration the requirement for cooling and energy lost (this number is considered as equal to 1.5).

Usually, it is estimated that a private cloud configuration has the utilization around 33% of available time. Therefore, the second factor of the equation 1 is related to this figure from the environment. In other words, this factor considers energy consumption from the corporate switches, as well as the data centre’s LAN.

3.3. **Service Consumption Analysis**

As it was mentioned in section 3.2, we adopted the proposed formula found in [2] for our service consumption analysis. The proposal states that the measure of energy consumption from a service, such as SaaS (Software as a Service), considers that a specific user is able to access an application in a cloud, where technical details are transparently.

Therefore, the energy consumption is summed up considering per usage from each user related to the terminal function, from where the service was required. Terminal can be understood as several devices that are shown in table 3, which can access services from a cloud configuration.

As stated in [2], the energy consumption from a user can be considered by the following equation:

\[
P_{sf} = P_{sf,pC} + \frac{1.5 P_{sf,sR}}{N_{sf,sR}} + 2 B_d 1.5 P_{sd} + A E_T \quad (2)
\]
Where, $P_{\text{tuc}}$ is the energy consumption from a user terminal, whereas $P_{\text{tec}}$ is the energy consumption from a server divided by the number of users that access this computational facility.

$B_d$ (bits) refers to the average size of a file. Ordinaries documents and spread sheets, usually, a conventional number used is 1,25MB. Inside the equation the multiplication for two means the redundancy factor.

$P_d$ refers to the power consumption from disk storage and $B_{sd}$ (bits) means the storage capability.

The A factor refers to data rate’s exchange between each user and servers. It is calculated by frames per second, because this service has a characteristic where computation and storage are executed by the cloud configuration. In other words, the terminal is used only as an output device.

$$A = 128 \times 1024 \times 24 \times Y \text{ b/s} \ (3)$$

As an example, it is possible to assume that the resolution of a terminal is equal to 128 x 1024, with a 24 bit color. The Y factor is the update rate from the terminal, which deserves the following explanation:

- It is considered a frame per second, the change of 100% of a user’s terminal per second. When only a part of the terminal received an update, only this part of the frame will be transmitted and accounted for the calculus.

$E_t$ is the basic energy consumption per bit for data transmission and commutation on the network.

4. **Cloud – Study Case**

In this section, it is illustrated the cloud environment utilized as a study case in our research. The object is to explain details from the cloud configuration, shown in figure 1, used for our experiments. The study case configuration has two main components, a corporate network and data center environment.

![Cloud configuration for study case](image)

4.1. **Corporate Network**

On the corporate side, available devices and power consumption are shown in tables 1 and 3. In table 1, it is possible to observe network devices used to access a cloud configuration (e.g. access and aggregation switches). On the other hand, table 2 shows examples of conventionally devices used to require services are personal computers, mobile telephones, tablets and laptops. All listed equipment will be included into the calculus of energy consumption.

4.2. **Data Center**

In this research work it is adopted a private cloud, which has a support from a small data centre. The configuration has architecture with two switches types (e.g. access and aggregation), two SMB servers and gateway router. This is a typical small cloud configuration.
In table 1, it is shown the BNG, Power Edge, Core Router and WDM as network devices, from the data centre configuration. These devices are characterized from their manufacturer’s specification with the bandwidth related to specific energy consumption. Sections should be numbered as follows:

| Network Device | Capacity | Energy Consumption |
|----------------|----------|--------------------|
| Switch Access  | HP/3COM 6600 | 176 Gb/s | 261W |
| BNG            | Juniper E320 | 60 Gb/s | 3.3 kW |
| P. Edge        | Cisco 12816 | 160 Gb/s | 4.21 kW |
| Core Router    | Cisco CRS-1 | 640 Gb/s | 10.9 kW |
| WDM800km       | Fujitsu 7700 | 48 Gb/s | 136 WChannel |

On the hand, table 2 illustrates servers which are, usually, used inside the core of a data centre. Computational cores are responsible for the executions of applications. The performance to execute an application is related to a number of characteristics, such as floating point, memory access and an appropriated parallel execution. All the data from this table were obtained from manufacturers’ specification. There are several energy consumption software tools that may be used also to build a similar table. However, looking for to use a more accurate set of numbers we assume information from the manufacturers.

| Servers Configuration | Processor Consumption | Device Consumption | Capacity |
|-----------------------|----------------------|--------------------|----------|
| HP Proliant D1360 G5  | 120W 135W            | 337W               | 800 Mb/s |
| Dell Power EdgeR710   | 80W 135W             | 376W               | 1,6 Gb/s |
| Storage Huawei        | 570W                 | 5,86 TB            |

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| Device Type | Processor Consumption | Device Consumption |
|-------------|----------------------|--------------------|
| PC-Desktop  | 10W 65W              | 120W               |
| Tablet      | -                    | 1-2W               |
| Notebook    | 2.5W 35W             | 40W                |
| Thin Client | 8W 8W                | -                  |
| Old PC      | 40W 103W             | 210W               |

5. Experimental Results
This section is characterized by two parts. In the first part, results from empirical experiments are presented. The use of the GreenCloud [11] simulator is utilized in the second part of the section. In addition, in the second part has some details related to the energy consumption. The objective, similar
to [13][14] and [15], was to learn how to calculate the energy consumption and then simulate computational and network elements from a specific configuration size.

5.1. Empirical Study Cases

Inside private clouds, where it is considered a universe of few users, it is possible to notice the high requirement of amount of energy necessary to transport data inside the configuration. This fact is especially true to the update rates from frames with high transmission rate.

Figure 2 shows energy consumption from several devices from our configuration, which represents a real cloud environment inside a large Brazilian organization. The figure it was generated by empirical results and from the calculus, using those formulas from section 3. The graphic presents a low energy consumption tendency when the number of users per server grows. On the other hand, the power consumption, related to transport (i.e. network devices) increases, to allow the greater flow.

Results presented in figure 2 represent the energy consumption per user in a private cloud with a universe of 20 users, with different devices and a comparison to an old fashioned computer.

The consumption of energy from the cloud can be considered low and stable, the threshold is characterized by 30W and 40W and the rate is 1 frame per second.

![Figure 2: Energy consumption per user in private cloud with 20 users](image)

The best case of energy consumption was verified by the tablet device, it is possible to verify that the required energy is very low, could be almost ignored for the calculus of power consumption. In contrast, the worst case was verified by desktop equipment which requires high rates of update. The figure from this equipment is similar to the old fashioned equipment, a Pentium 4, a machine which does not have any energy manager tool.

A private cloud has one advantage, in comparison to public cloud configuration, because it has a small network infrastructure. Thus, this element has a low weight for the power consumption calculus.

Figure 3 shows a study case of energy consumption per user in a private cloud with 200 users and a comparison with power consumption of a new notebook. It is possible to verify a sharp drop on energy consumption, where the threshold is located between 5W and 10W.

Results shown in figure 3 were led by the low energy consumption from infrastructure equipment to support the high number of users. These results indicate that cloud configurations are interesting environments for a large number of users that can reduce costs related to power consumption per user.

Another fact to be observed is the throughput from servers. In this study case, the upper throughput limit from the server was 800 Mb/s. Therefore, the graphics stopped at 0,12 frames/s, because this is the server limit to a configuration with 200 users.

In addition, it is interesting to observe that the energy consumption for the Dell notebook was equal in the case of direct access and to access the cloud configuration. However, this figure was not true for the access from small devices (e.g. tablets), where the energy consumption was different.

5.2. GreenCloud
In a second stage of our research work we considered the utilization of the GreenCloud simulator [11]. Table 4 shows all chosen parameters, these values were selected to provide a similar configuration to the designed cloud environment.

Analysing figure 4, it is possible to notice the high costs of energy related the network infrastructure for the small data centre. This fact reaffirms our assumption, which it is also stated in similar research works (e.g. [10]). This consumption number can represent circa from 10% to 20% of the data centre budget.

There is an indication, when using the GreenCloud simulator package, of the influence in the use of the Dynamic Voltage/Frequency Scaling (DVFS) and the Dynamic Shutdown (DNS) related to power consumption from the devices. Thus, it is important to notice two factors:

- **Servers**: in the case of these devices there is a clear advantage in terms of energy management saving when the DVFS is used together with DNS. This utilization produce a workload balancing among servers, avoiding peak consumption, as it is shown in figures 5 and 6;

- **Network devices**: because our research work was based on a small private cloud configuration, with a small number of applications submission, we reached the 1W of power consumption. Adopting the use of DVFS and DNS for switches and routers, it was possible to reduce unnecessary energy consumption from ports and linecards. These two elements are responsible for the major energy consumption from network devices.
We analysed an energy bill from the real environment, which was used as a configuration for this study, without and with DVFS+DNS management. In this analysis it was considered factors such as IT, light, cooling, lost and others.

The PUE number, without energy management, was equal to a 1.63, where the total energy per month was 28,944 kWh and the consumption from the IT was 17,744 kWh. In contrast, the PUE number, with energy management, was equal to 1.76, where the total energy per month was 11,650 kWh and the consumption from IT was 6,600 kWh.

6. Conclusions and Future Work
This paper it was presented a research study case which had the goal to analyse the energy consumption from a cloud configuration, considering computational resources and network devices. Therefore, a corporate network and one small data centre were configured as a private cloud configuration. Measures from empirical experiments had shown that the data transport inside the configuration have an influence in the power consumption. Inside the private cloud configuration, our results indicated the efficiency of this environment in comparison to the utilization of standalone computers. In addition, the experimental results indicate the advantage of simultaneous utilization from several users. This fact can be explained by the enhanced distribution of cost of energy consumption through all users from the cloud. In addition, we used the GreenCloud package, where executing some simulations of the configuration, without and with energy management, pointed out an energy saving number of around 37%. On the other hand, the PUE calculus showed that some elements (e.g. lost fraction) should also take into consideration to provide a more accurate number of efficiency.
As a future work, we plan to utilize a set of scheduling algorithms to submit applications to a cloud environment, considering an energy consumption factor. Thus, it will provide a more green approach for the cloud configuration.

Table 4: Parameters utilized in the GreenCloud

| Parameters | Data centre Architecture |
|------------|--------------------------|
| Switches   | 2 Layers                 |
| Core       | 1                        |
| Aggregation| 2                        |
| Access     | 2                        |
| Servers    | 4                        |
| Links      |                          |
| Core - Aggregation | 10 Gb  |
| Aggregation| 1Gb                      |
| Access     | 1Gb                      |
| Access - Servers | 1Gb  |

| Data centre load average | 30%  |
| Tasks size              | 4500 (3 Ethernet frames) |
| Simulation time         | 30, 60, 90, 120 minutes |

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