An analysis of the Power Usage Effectiveness metric in Data Centers

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Abstract— **During the last decades the growing demand for computer infrastructures and software has led to important increased in the number and the dimension of data centers. The energy used by the data centers (here are included the power for IT equipment and the power for the cooling infrastructure) has increased dramatically. The paper proposes an analysis of Power Usage Effectiveness (PUE), the classical metric for measuring energy efficiency in Data Centers (DC). A discussion of its advantages and of its shortcomings is presented. Some complementary metrics and new metrics for improving PUE are synthesized. This analysis can help researchers to identify the main trends of Energy Efficiency assessment in DC.**

Keywords—green Data Center, energy efficiency metrics, measurement, Power Usage Effectiveness, carbon footprint

I. INTRODUCTION

The last decades have proved important progresses in the development of Data Centers (DCs) that primarily contain computers used for data storage, data processing and networking. Today DCs are found in nearly every sector of the economy: business, universities, government and many others.

Now DCs play an important role in modern Information Technology (IT). The development of cloud computing, during the last years has lead the DCs growing in number and size. Large-scale public cloud DCs are called hyperscale DCs. The number of these DCs will grow from 259 at the end of 2015 to 485 by 2020. They will represent 47 percent of all installed DCs by 2020 [1].

The energy used by the DCs (here are included the power for IT equipment and the power for the cooling infrastructure) has increased dramatically. The energy consumption is a important problem for DCs. The power draw for DCs ranges from a few Kilowatts for a rack of servers to several tens of Megawatts for large facilities.

The inefficient management of DCs conduct to high energy consumption and carbon footprint. The "Code of Conduct for Data Centers" was created in response to the increasing energy consumption in the DCs commercial sector. It is a voluntary initiative managed by the European Commission's Joint Research Centre, with the aim to reduce energy consumption through energy efficiency measures. The Code of Conduct is an independent scheme in the EU to certify that a DC has adopted energy efficiency best practices [2].

The concept of a DC include all of the resources and infrastructures for power distribution, Heating, Ventilation and Air Conditioning (HVAC) control. Contains also levels of elasticity and security that are needed to assure the service accessibility [3], IT and HVAC equipment are the two major energy end-users. IT equipment consumes electrical energy but also generate very high internal heat loads. The HVAC systems in return consume more energy to remove the heat and maintain the proper indoor operating conditions [4].

For measured data in DCs large variations can be observed in different facilities given the evolution of equipment efficiencies or depending on the type of cooling and air-handling system. The HVAC consumes 33% of DC energy use and 18% is for the Computer Room Air Conditioning (CRAC) unit. Servers are the main energy consumers in a DC (45%) [4]. The power consumption of a computing server is proportional to the CPU utilization. It is important to reduce energy consumption for servers and cooling systems and that is the key issue of the sustainable development of data centers.

A green DC is a repository for the storage, management, and dissemination of data in which the non-IT infrastructure (which includes the mechanical, lighting, electrical and computer systems) is designed for maximum energy efficiency and minimum environmental impact [5] .

Motivated by the high energy consumption and the low utilization of resources in DCs, many research efforts over the past few years have focused on the design of green DC infrastructures and services.

The paper proposes an analysis of PUE, the classical metric for measuring energy efficiency in DCs. In the second section of the paper the Power Usage Effectiveness (PUE) metric is surveyed. A general scheme for the PUE computation is presented. The third section contains a discussion of PUE advantages and shortcomings. Some complementary metrics and new metrics for improving PUE are synthesized in the fourth section. This analysis can help researchers to identify the main trends of Energy Efficiency assessment in DC.

II. THE PUE METRIC

In order to estimate the efficiency and compare the power consumption of DCs, it is necessary to have indicators of energy efficiency accepted by all. The first step on greening the DCs is to identify the energy efficiency metrics. For

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efficient and sustainability of DCs, it is necessary to monitor all the components of a DC. There are many different energy efficiency metrics, each having its own advantages, disadvantages and limitations. The first metric introduced in 2006 by C. Malone and Christian Belady is Power Usage Effectiveness (PUE) [6]. PUE calculates the energy efficiency of a DC. It is defined as [6]:

$$PUE = \frac{Total\_Facility\_Energy}{IT\_Equipment\_Energy} \tag{1}$$

where:

- *Total_Facility_Energy* is the total power used in DC
- *IT_Equipment_Energy* is the power used for IT equipment.

According to Avelar [7], *IT_Equipment_Energy* is the energy requirements associated with all the major IT components of the DC, such as server, storage, network, and other devices.

Total_Facility_Energy is energy requirement for major components plus other supporting infrastructure: (a) power delivery components (UPS systems, switchgear, generators, power distribution units, batteries, and distribution losses external to the IT equipment), (b) cooling system components (chillers, cooling towers, pumps, computer room air handling units (CRAHs), computer room air conditioning units (CRACs), and direct expansion air handler (DX) units), (c) other miscellaneous component loads, such as DC lighting [7].

Another definition of PUE is:

$$PUE_{f,p} = \frac{Total\_facility\_energy}{IT\_equipment\_energy} \tag{2}$$

where:

- *f* is the Data Point Collection Frequency: year, month, or week
- *p* is the Metering Position: Basic (UPS output), Intermediate and Advanced (at IT equip.)

Partial PUE (*pPUE*) takes into consideration all of the infrastructure components and it is a metric for energy use within specified limits which partitions the DC into zones. The limits could either be physical or logical (e.g. all cooling components, all power components, and all departmental components) [8].

$$pPUE = \frac{Total\_power\_within\_a\_zone}{IT\_equipment\_power} \tag{3}$$

Energy within the zone (note: *pPUE* can only be calculated for zones with IT):

$$pPUE(zone) = \frac{(Non\_IT\_power(zone) + IT\_equipment\_power(zone))}{IT\_equipment\_power(zone)} \tag{4}$$

A general scheme for the PUE computation is presented in Figure 1.

By definition, the PUE cannot be less than 1. From an energy point of view, a PUE of 1 would represent an optimal efficiency for the DC. However, this would mean that the DC in question does not have any equipment for the cooling or the security of the computer equipment. Moreover, this indicator is criticized [9] because the electrical energy consumed by the servers fans is counted in the energy consumed by the servers.

Between 2000 and 2010, the worldwide DCs average PUE value has decreased from about 2.0 to a value between 1.83 and 1.92 [10]. A study by the U.S. Environmental Protection Agency (EPA) found an average PUE of 1.92 based on a voluntarily submitted survey of 120 DCs, which may represent an optimistic estimate of the actual average. Possible minimum PUE may depend on the climate conditions and/or geographic locations [10].

According to the Uptime Institute's 2014 DC Survey, the global average of largest DCs is around 1.7. Levels of DC efficiency by PUE value can be seen in Table I [10]. The average PUE for all Google DCs is 1.12 in 2017, making Google DCs among the most efficient in the world [10, 11].

TABLE I. LEVELS OF DC EFFICIENCY BY PUE VALUE [10]

PUE	Green Grid rating system	PUE	EPA rating System
3.0	Very inefficient		
2.5	Inefficient	1.9	Current Trends
2.0	Average	1.7	Improved Operation
1.5	Efficient	1.3	Best Practice
1.2	Very Efficient	1.2	State of Art

III. A CRITICAL ANALYSIS OF THE POPULAR METRIC PUE

Though widely used, PUE has industry-acknowledged shortcomings in terms of accuracy. In the following we shall study the PUE metric in more detail providing a critical analysis of its use. PUE can be considered the victim of its own success.

Transformed prematurely from a metric designed to help increase the energy efficiency of the DCs in an aggressive marketing element, PUE had part of criticism from the beginning. Over time, the indicator has not lost its overall attractiveness, but at the present moment the expert's opinion is divided - some think that the PUE has strengthened its position on the market, while others think that it has

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considerably diminished relevance, becoming just one element from a much larger picture.

An important problem is that PUE does not take into account the climate of the region where the DCs are built. In particular, it does not take into account various normal temperatures outside the DC. For example, a DC located in a Nordic country cannot be compared to a DC located at the Tropics. A colder climate do not need for a massive cooling system. The energy consumption of cooling systems represents about 30 percent of consumed energy in a facility, while the energy consumption of DC equipment represents about 50 percent. Due to this fact, the DC located at Tropics may have a final Power Usage Effectiveness greater than PUE of the DC located in a Nordic country. This may happen even if the DC located at Tropics may be running overall more efficiently than the DC located in a Nordic country.

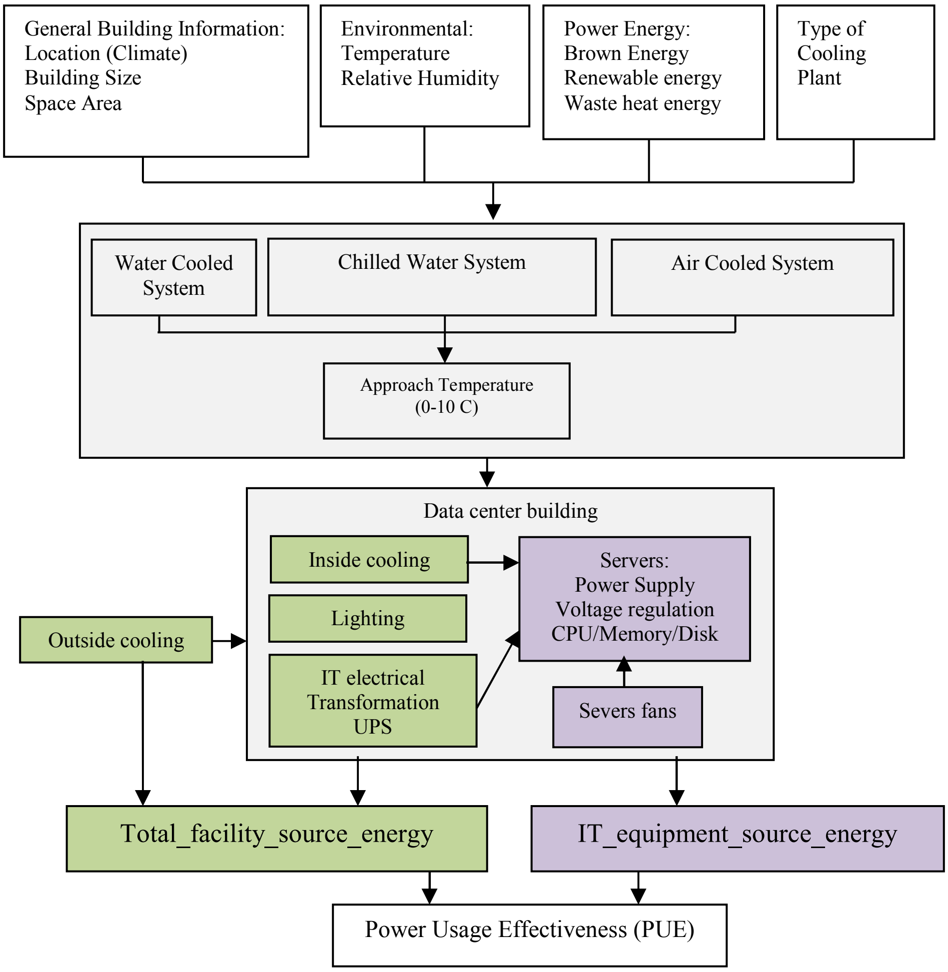

Figure 1. A general scheme for the PUE computation

An interesting remark is that PUE should be measured when the IT equipment is working at full capacity. Otherwise an estimated PUE is practically meaningless. The existence of stable power grids, low energy prices and of the year-round access to “free cooling” drove a number of large Internet companies to build DCs in the Nordic countries. At that locations the DCs could achieve extremely low PUE values. Google DCs in Finland and Facebook DCs at The Node Pole in Sweden are two such examples. Very interesting from an economic perspective is that, for some locations in Nordic countries, the DC managers can use the outside air for cooling all year round. This method reduces very much PUE. Since in Nordic countries the outside air for cooling can be used 12 months of the year, the air cooling systems used during warm days can be down-sized.

Another problem raised by the use PUE is the fact that many centers use it to measure this indicator for limited periods of time. Or, in order to have a really relevant value, is needed a continuous or a periodic measurement. The final rating will be based on the recorded average values. Other relevant criticisms are focused on the fact that PUE cannot make comparisons between DCs with various orders of size, configurations, technologies and having locations in different geographic areas.

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Another essential element that we need to take into account when analyzing the PUE indicator is the size of the investments made to increase energy efficiency.

There are several other issues associated with PUE. In [9] is discussed the impact of virtualization on PUE. For instance, if IT specialists may choose to implement virtualization in order to reduce the total power consumption of the IT equipment then PUE increases, since the power used by the infrastructure components likely do not decrease proportionally with the power consumed by the IT equipment [12]. In addition, infrastructure for cooling may perform less efficiently because it is under-loaded further worsening PUE. It is necessary to include the server utilization factors in the PUE metric definition [12], otherwise, situations like these can make PUE less informative in sustainability discussions. These above mentioned situations can bring confusion among system managers who base their energy related decisions on minimizing PUE.

IV. Complementary metrics to PUE

PUE performs very well if its limits are respected. Therefore, it is proposed to use complementary metrics to PUE. A synthesis of this metrics is presented in Table II.

In the following some new research on PUE complementary metrics are presented.

A globally accepted metric on the energy efficiency of computer servers in business applications is still missing, despite a great interest from stakeholders.

Besides PUE and DCiE, there are several other metrics used to determine the energy efficiency of a DC.

In the context of the implementation of the European Ecodesign Directive [13], a detailed analysis has been carried out on the feasibility of policy requirements for computer servers addressing, among others, the relation between energy use and performance [14]. In [14] a proposal for a new server metric was developed.

The new server metric is based on SERT (Server Efficiency Rating Tool) [15] . SERT is recognized among the best methods for servers characterization. SERT uses several common computation tasks via workless, i.e. simulations of real working environments tailored to test discrete system components (e.g. processors, memory and storage) and subsystems, such as RAM (random access memory) and CPU (central processing unit).

In the paper [16] a summary of 100 DCs air conditioning energy performance is presented. Additionally several energy efficiency metrics and benchmarks are provided. The operators can use this information to track the performance and identify opportunities to reduce energy use of air conditioning systems in their DCs.

In [17] the state-of the-practice of power measurements and energy efficiency techniques in the data center industry was investigated. The method used was interview with practitioners and DCs managers from four companies of different size.

In order to analyze the relation between the IT and the power infrastructure, two new metrics for measuring energy efficiency were proposed in [18]. The first metric is the power variability (PVar) that indicates the relative rates and heights of power variations. The second metric is called the infrastructure power adaptability (IPA). It relates the power variability and the relative average deviations of IT and the power infrastructure in order to represent the scalability and adaptability of the infrastructure to the IT demands. Both metrics use the same input data. They allow for a continuous PUE calculation for a running DC.

Current approaches for assessing the operational efficiency of the DCs are mostly static. They do not take into account the flexibility aspects of modern DCs and fail to reflect the effects of DC optimization on their sustainability profile. In [3] were proposed new metrics for the evaluation of DC energy efficiency. The metrics are: 1) *Adaptability Power Curve* (APC), 2) *Adaptability Power Curve at Renewable Energies* (APC*ren*), 3) *DCAdapt* (DCA), 4) *Grid Utilization Factor* (GUF), 5) *Energy Reuse Effectiveness* (ERE), 6) *Primary Energy Savings* (PE Savings) and 7) *CO*2 *avoided emissions* (CO2Savings).

As a result of the introduction of PUE (Power Usage Effectiveness) as a performance metric the number of energy efficient DCs has increased. PUE’s simplicity and focus on infrastructure efficiency was quickly adopted by the industry, but now the question is raised if PUE is still able to lead the quest for improved energy efficiency. PUE does not show performance regarding IT efficiency, water usage, heat recovery, on-site energy generation or carbon impact. This can lead to misuse of PUE by focusing on just improving PUE values instead of real energy use. In the paper [19] an improvement of the DC performance assessment is proposed by extending the scope beyond the PUE.

V. Conclusions.

An overview of PUE metric and a critical analysis was made. Despite of its shortcomings, PUE has remained an important metric for the evaluations of energy efficiency of DCs. DCs managers are continuously implementing new innovations in order to improve their scores. Our contribution motivates the quest for new metrics for the assessment of DCs energy efficiency. This thing is necessary in order to attain sustainability goals.

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TABLE II. COMPLEMENTARY METRICS TO PUE

Name and Acronym	Unit	Type	Opt	Formulas	References
Carbon Usage Effectiveness CUE	$\frac{kgCO_2}{kWh}$	Min	0	$CUE = \frac{Total\_CO2\_Emmision_{DC}}{IT\_equipment\_Energy}$	[20]
Energy reuse ERF	Percent	Max	1	$ERF = \frac{\mathrm{Re}use\_energy}{Total\_Energy}; \quad 0 \le ERF \le 1$	[21]
Water usage WUE	Liters/kWh	Min	0	$WUE = \frac{Water\_usage}{IT\_Energy}; \quad 0 \le WUE$	[22]
IT Equipment Utilization ITEU	Percent	Max	1	$ITEU = DC\_IT\_Equip\_util\_rate = = \frac{Total\_measured\_energy\_IT\_equip}{Total\_specification\_energy\_IT\_equip}$	[23]
IT Equipment Energy Efficiency ITEE	Capacity/ kWh	Max	∞	$ITEE = \frac{TotalIT\_equip\_ratedWorkcapacity}{Total\_rated\_energy\_ITequip}$	[23]
Green Energy Coefficient GEC	Percent	Max	1	$GEC = \frac{Total\_Green\_Energy_{DC}}{Total\_Energy\_Comsumtion_{DC}}$	[23]
Data Center Performance per unit Energy DPPE	Work/ kWh	Max	∞	$DPPE = \frac{DC\_Work}{Carbon\_Energy} = = ITEU * ITEE * \frac{1}{PUE} * \frac{1}{1-GEC}$	[23]
Energy Reuse Effectiveness ERE	Percent	Min	0	$ERE = \frac{Total\_Energy\_\mathrm{Re}used}{IT\_equipment\_Energy} = = (1-ERF) * PUE$	[24]
Data Center Infrastructure Efficiency DCiE	Percent	Max	1	$DCiE = \frac{1}{PUE}$	[25]
Data Center Productivity DCP	Useful work / Watt	Max	∞	$DCP = \frac{Useful\_work}{Total\_facility\_Power}$	[26]

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