PUE or GPUE: A Carbon-Aware Metric for Data Centers

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***Abstract*—Greening Information and Communication Technology (ICT) sector is extensively undertaken globally. Metrics were announced to control ICT impacts. For example, Power Usage Effectiveness (PUE) metric was developed to report the effectiveness of consumed power in the data center. Consequently, researchers and developers produced several prototypes and implementations on green data centers and they claimed the accuracy of their solutions with wrongly understood metrics. In this paper, we review PUE metric and its green extension (GPUE), in addition to a review of green determinants on data centers. Then, we demonstrated the application of PUE and GPUE in a modern and recent green data center (the Parasol data center). Our demonstration showed the impact of Parasol data center, and reveal insights on how to improve the carbon footprints of the data center.**

***Index Terms*—carbon footprint, data center, power metric, PUE, GPUE.**

I. Introduction

A global intention is giving to greening ICT sector and power related metrics were announced. For example, the development of Power Usage Effectiveness (PUE) was released by The Green Grid at the end of the last decade. On the other hand, industry and academic researchers focused to enhance and cap ICT with these metrics. An example, greening data centers is undertaken by industry (e.g. HP and Google) and academia. Several solutions were suggested with multiple disciplinary, and they claimed the efficiency of their solution according to these metrics. However, a leak of an understanding of the metric could have resulted in vague claims toward such important impacts (as in our case the environment impacts).

In this paper, we review an important power metric used to evaluate data center effectiveness. Further, we discuss a green extension of this metric. Data centers mainly consist of racks of servers and interconnected devices, cooling systems and other peripherals (see fig. 1). Furthermore, we analysis the green determinants in data centers. In addition, we demonstrate the impact of such metric on evaluating modern and recent green data centers such as Parasol data center. Our demonstration insight us on how to apply such a metric and reveal improvements in the green data center to become more eco-friendly and less carbon footprint.

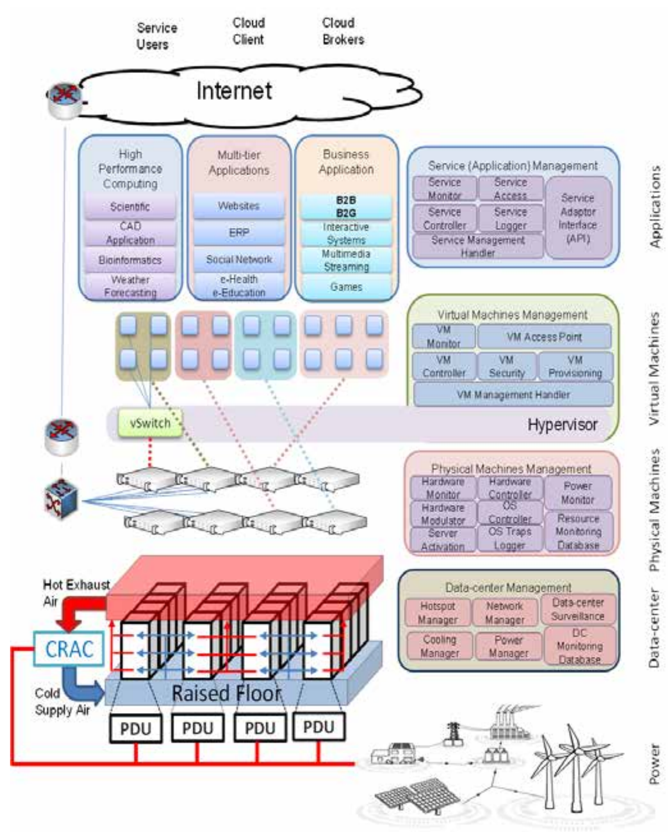

Fig. 1: Data center logic architecture.

The rest of this paper is organized as follows. Power usage metrics reviewed in Section II. Analysis of green data center determinant discussed in Section III. An application of the metric on modern data center was demonstrated on Section IV. Lastly, a conclusion with reviews provided in Section V.

II. Power Usage Metrics

There are many metrics used to observe the power in data centers. For example, the performance per watt is the energy efficiency of computer hardware per watt, it is found in literature as Floating Point Operations Per Second per watt (FLOPS per watt). However, a well-known power usage metric is the Power Usage Effectiveness (PUE); which is easy to observe and report to data center's administrator. Apparently, PUE is not focused to evaluate the CO2 emission per watt per unit time for the data center; therefore, in the following subsections, we are reviewing the PUE and the extension of Green PUE (GPUE).

A. Power Usage Effectiveness (PUE)

Power Usage Effectiveness (PUE) is a metric used to evaluate the power efficiency of a data center. Conceptually, PUE is the ration of the power used by IT appliances and equipment in a data center to the overall amount of power that is consumed in the data center, as in eq. (1). PUE initially developed by The Green Grid, and it is undertaken for extended versions [1].

$$PUE = \frac{Total\ Power\ Used\ in\ Data\ Center}{IT\ appliances/equipment\ power}. \quad (1)$$

The ultimate goal of any data center is using the power only for computing resources usage, namely IT appliances and equipment, and that practically leads the data center's PUE to become 1. Therefore, different fields were merged to improve the PUE of data centers, such as power optimization models, data center's thermal controllers, and renewable power suppliers.

B. Green Power Usage Effectiveness (GPUE)

PUE consider the usage of power but it is not focused on what type of power is used in a data center. For example, if a data center owns its renewable power supplier or purchased a green-generated power for operation, that is not comparable with other data centers that use power generated from harmful suppliers such as coal (see Table I). Greenqloud in [6] suggested an extension of PUE calculation that included the power source CO2 emissions. In this suggestion (denoted as GPUE), the evaluation of data center impact on the environment could be clearly visible. The below eq. (2) is illustrating how to evaluate the GPUE according to the type of supplied power in a data center:

$$GPUE = G * PUE, \quad (2)$$

where G is the weighted sum of energy sources and their life-cycle kg CO2/KWh, or mathematically as in eq. (4)

$$G = \sum \%Energy\ Source\ x(1 + weighted). \quad (3)$$

Finally, we could correlate the presentation of GPUE with the existence of PUE as below:

$$GPUE = G@PUE. \quad (4)$$

Further applications of GPUE are illustrated in remaining sections.

TABLE I: Life-cycle estimates for electricity generators. Reproduced from [2]

Energy Source Technology	G CO2/kwh
Wind (offshore)	9
Hydroelectric reservoir	10
Wind (onshore)	10
Biogas	11
Hydroelectric river	13
Solar thermal	13
Biomass	14-41
Solar PV	32
Geothermal	38
Nuclear	66
Natural gas	443
Fuel cell	664
Diesel	778
Heavy oil	778
Coal (with scrubbing)	960
Coal (without scrubbing)	1050

III. Analyses of Green Data Centers

Data centers are generally evaluated according to the ratio of power used to operate IT equipment to the total power consumed in the data center. However, in the era of green computing, a carbon-aware metric is needed to evaluate accurately the CO2 emission per watt used in the data center. In this sense, we could judge the impact of a data center on the environment according to how much CO2 emissions it produces.

In literature, there are two main efforts to reduce the carbon footprints and improve the power usage efficiencies in data centers. First, the introduction of green suppliers in data centers to reduce CO2 emissions. Second, the optimization of the power used by none IT facilities is controlled.

A. Type of Power Supplied

In the past, the data centers were power with the stable power supply coming from the utility grid. The main benefit of the utility grid is the stability and on-demand supply. Nonetheless, data center's administrators considered backup power system such as local diesel generator installed on the site. Both utility grid and backup generators are not eco-friendly solutions, and they increase the carbon footprint of the data center. Therefore, efforts have been done to engage renewable to power the data center [3]–[5]. These efforts showed a reduction of carbon footprints as reported in [6], however, an extra burden of maintaining these renewable systems is escalated. An interesting effort between government regulators and industry toward increasing the utilization of renewable in data centers has its place [7]. Extra generated renewables (not needed by data centers) were permitted to be sold out to the utility grid and issuing Renewable Energy Certificates (REC) [7], [8]. Conversely, efforts of tracking renewable geographically were introduced as a reducer of carbon footprints in data centers [9]–[11]. However, these efforts have added extra management tasks for the data center; which is data center inter-operability management (for inter-datacenter!).

B. Thermal Control

PUE is extensively affected by none IT facilities, and industry is maximizing the per watt profit in their data centers. A cooling system in a data center is vital yet is power consumption. A reputable contribution of HP Lab in managing computer room air condition (CRAC) in their data center [12] was influencing a lot of thermal control researches in data centers [13]–[15]. Apparently, these efforts were considering sensors and thermal tracking in the data center to reach the optimum cooling system and minimum power usage.

IV. Application

Evaluating the efficiency of a data center according to PUE is imprecise because the PUE itself cannot illustrate the carbon footprint, therefore it is difficult to recognize how much data center is green (or eco-friendly). For instance, in [5], a small-scale data center with solar photovoltaic (Solar PV) and energy storage was built. The data center includes a free cooling system and HVAC system (HVAC was used around %8 of time). Authors claimed that they reduced the carbon footprint in this data center through the control of the utility grid dependent, a minimum of %36 reduction (in some cases up to %100 reduction) dependent on utility grid was achieved. However, we argue that this data center could reduce its carbon footprint better than the current setup. Basically, we reviewed the configuration of the Parasol data center as in the below Table II. And the PUE of Parasol data center could be calculated as follows:

$$
\begin{aligned}
PUE &= \frac{Non\ IT + IT\ Computing}{IT\ Computing} \\
&= \frac{(\%8\ cooling * 2.3Kw) + (80w) + (64*30w) + 2*42w}{(64*30w) + (2*42w)} \\
&= 1.13.
\end{aligned} \quad (5)
$$

TABLE II: Parasol reviews. Reproduced from [5].

Infrastructure	Technology Description	Power usage (watts)
None IT equipment	From Solar Panels (DC) to IT equipment (AC) power converting*	%2 of generated energy from solar panels
	HVAC (%92 free cooling)	100-2.3 k watts
	Monitoring Server (Quad-core Xeon server)**	80 watts**
IT computing facilities	64 Atom-based servers	(each 30 watts) 1.920 k watts
	Cisco switches	(each 42 watts) 84 watts

** DC-to-AC is not included in PUE evaluation. ** This server, however it is an IT equipment; it is not a computing resource in data center. In addition, its power usage was not mentioned in the reference but to the best of our knowledge, this server is consuming 80 watts.*

However, if we considered the GPUE as a carbon footprint observer where the Parasol data center was operated %36 %100 on Solar PV, we incur the Parasol was running on GPUE of 1.683 1.032@1.13. Therefore, the amount of Kg CO2 per usable kWh is (G-1) x PUE=0.77 0.03 kg.

We inferred that if we added or replaced the Solar PV (as a solar PV energy generator technology) with less CO2 emission per watt technology such as wind or biogas, a data center could reflect much effectiveness of carbon footprint. For instance, if we added a wind turbine with the existing setup, we could achieve (at moments) a carbon footprint of 0.01 kg of CO2 per usable kWh.

V. Conclusion

Understanding metrics are vital prior to claiming the effectiveness of a solution. In this short paper, we have reviewed a well-known power metric in a data center's evaluation called PUE and reviewed its green extension (GPUE). We have applied the metric to a modern green data center to evaluate its carbon footprint. Through our demonstration, we have inferred that GPUE metric is easier than PUE metric to display the amount of CO2 emission produced by data centers. For instance, a modern green data center such as Parasol data center has a PUE of 1.13 while it has a varying production amount of CO2 emission (0.03 to 0.77 Kg CO2 per usable kWh).

Lastly (but not least important), adequately applying a metric could insight us on how to improve the environmental impact of data centers and further greening the ICT. For instance, the Parasol data center could be improved by adapting less carbon footprint energy generator technology such as wind and biogas. In fact, it could reduce its production of CO2 emission (wind technology could achieve about 0.01 Kg CO2 per usable kWh).

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