

Green Technology, Cloud Computing and Data Centers: the Need for Integrated Energy Efficiency Framework and Effective Metric

Nader Nada
Fatih University
Istanbul, Turkey

Abusifian Elgelany
Sudan University
Khartoum, Sudan

Abstract—Energy efficiency (EE), energy consumption cost and environmental impact are vibrant challenges to cloud computing and data centers. Reducing energy consumption and emissions of carbon dioxide (CO₂) in data centers represent open areas and driving force for future research work on green data centers. Our Literature review reveals that there are currently several energy efficiency frameworks for data centers which combine a green IT architecture with specific activities and procedures that led to decrease the impact on environment and less CO₂ emissions. The current available frameworks have some pros and cons that is the reason why there is an urgent need for an integrated criterion for selecting and adopting energy efficiency framework for data centers. The required energy efficiency framework criteria should also consider the social network applications as a vital related factor in elevating energy consumption, as well as high potential for better energy efficiency in data centers. Additionally, in this paper, we highlighted the importance of the identification of efficient and effective energy efficiency metric that can be used for the measurement and determination of the value of data centers efficiency and their performance combined with sound and empirically validated integrated EE framework.

Keywords—Cloud Computing; green Cloud; Datacenter; Energy efficiency

I. INTRODUCTION TO GREEN TECHNOLOGY IN CLOUD COMPUTING

Cloud computing is a promising area in distributed computing. Data centers are the main component of cloud computing. Data centers energy consumption cost and environmental effect are dynamic challenge to cloud computing. Additionally, the growing usage of social applications and the expansion of e-business require an increase in the number of data centers. However, the combination of global warming and inconsistent climate make the cost of energy a major challenge for the sustainability of e-business [1]. It is a corner stone of the infrastructure of cloud computing approach by which a variety of information technology (IT) services were built. They extended the ability of centralized repository for computing, hosting, storage, management, monitoring, networking and deployment of data.

With the rapid increase in the capacity and size of data centers, there is a continuous increase in the demand of energy consumption [2]. Data centers, beside their ongoing high energy consumption, also produce carbon dioxide that riddled with IT inefficiencies. International Data Corporation (IDC) annual report found that cloud computing reached \$42bn in 2012 and the revenue of cloud in 2013 was \$150bn [3].

Environmental impact of Information Technology (IT) under the banner of “Green IT” was been discussed by academia, media and government Since (2007), when the Environmental Protection Agency (EPA) submitted a report to the US Congress [5] about the expected energy consumption of data centers. Since then Green IT has been receiving growing attention. The overall objective of Green IT is to increase energy efficiency and reduce CO₂ emissions [6], figure 1 represents the effect of good practice of green data centers to gas emission. There are two ways to make data center greener: First, improve energy efficiency of data center, second, use clean energy supply. Cloud computing has different techniques to solve energy-efficient problem by minimizing the impact of cloud computing on the environment. These techniques deal with energy efficiency consumption like virtualization, hardware base, operating systems base and data centers. Some new features arise like energy performance, and time wise. However, the concerns should be to swap problem between energy consumption and performance.

II. LITERATURE REVIEW ON ENERGY EFFICIENCY FRAMEWORKS FOR CLOUD COMPUTING

In our literature review below is based on previous studies of investigated energy efficiency on cloud computing and focused on data center technology.

Asghar Sabbaghiet al.[9], investigated previous researches and introduced energy efficiency framework on information technology that enabled Green supply chain management. They proposed a unique conceptual taxonomy of information technology for sustainability. They also identified the relationship between Green supply chain management information flow, IT governance and Green infrastructure components.

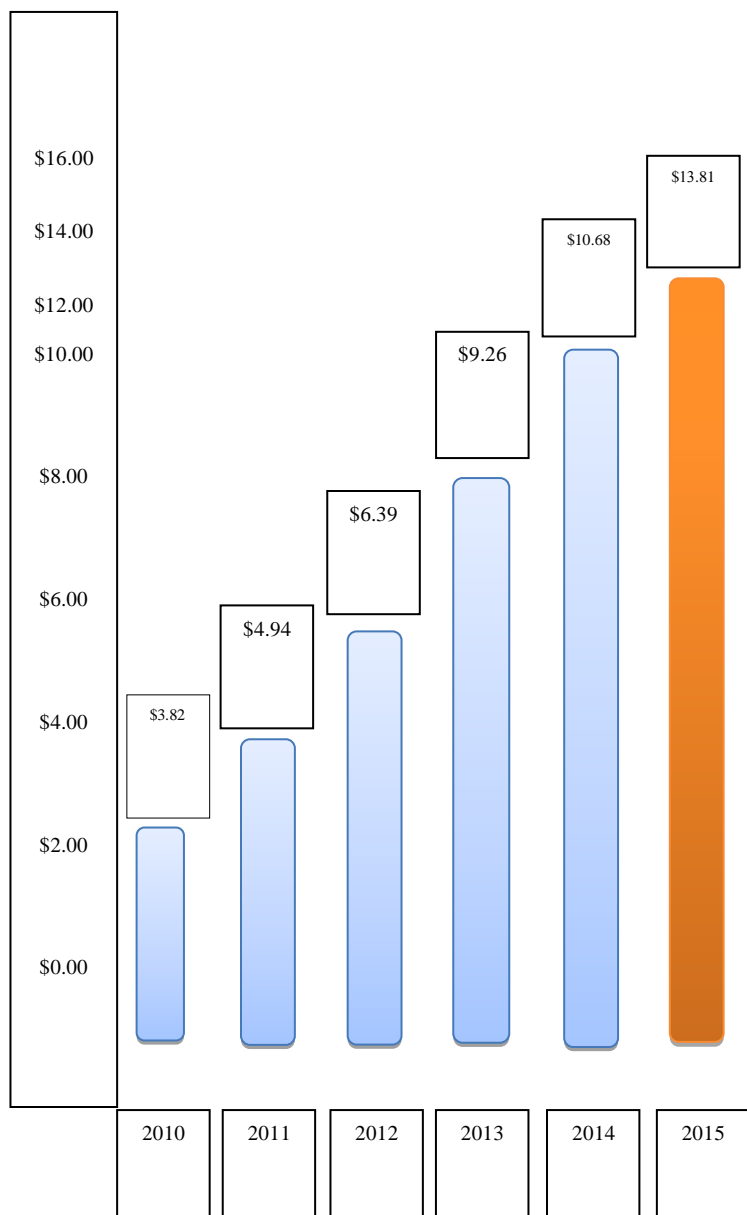


Fig. 1. Green Data Center Market Value [7]

Zhiming Wang et al.[10], proposed mechanism to support maximizing resource utilization by using active and idle energy consumption by finish time minimization. This mechanism reduces the power consumption by allowing spare servers to be in idle state. This mechanism put into account QoS of cloud datacenter.

RajkumarBuyya et al.[11], proposed a novel mechanism in three ways: (a) architectural principles for energy-efficient management of Clouds; (b) energy-efficient resource allocation policies and scheduling algorithms considering QoS, and devices power usage characteristics; and (c) a novel software technology for energy-efficient management of Clouds.

Anton Beloglazov et al.[12], developed a unique mechanism which supports dynamic consolidation of VMs based on adaptive utilization thresholds, which put into account Service Level Agreements (SLA).

Nguyen Quang Hung et al.[13], proposed unique server selection policy, and four algorithms solving the lease scheduling problem. This approach reduces 7.24% and 7.42% energy consumption than the existing greedy mapping algorithm.

Uddin et al.[14]and his team introduced a unique framework to improve the performance and energy efficiency of data centers. They developed a classification mechanism for data center components depending on different resource pools and different parameters like energy consumption, resource utilization, workload, etc. The framework highlights the importance of implementing green metrics like Power Usage Effectiveness (PUE) to measure the efficiency of data center in terms of energy utilization and carbon dioxide (CO₂) emissions. The framework is based on virtualization and cloud computing to increase the resource utilization of already installed servers from 10% to more than 50%.

Meenakshi Sharma et al.[15],developed a new mechanism with two steps: firstly they developed an analysis of different Virtual Machine(VM) load balancing algorithms, second introduced a new VM load balancing algorithm that has been developed and implemented in Virtual Machine environment of cloud computing in order to achieve better response time and cost.

In S. Kontogiannis et al.[16], the research team developed a unique mechanism called Adaptive Workload Balancing algorithm (AWLB) for cloud datacenter based web systems which deals with agents into two dimensions the web datacenter and web servers. AWEB algorithm also supports protocol specification for signaling purposes among web switch and datacenter nodes and also utilizes other protocols such as SNMP and ICMP for its balancing process. Performance gains are shown from tests of AWEB against known balancing Least Connections (LC) and Least Loaded (LL) algorithms. Table 1 represents the summary of our literature review on cloud computing energy efficiency frameworks and techniques.

III. URGENT NEED FOR ENERGY EFFICIENCY INTEGRATED FRAMEWORK FOR CLOUD COMPUTING AND DATA CENTERS

Reducing energy consumption and emissions of carbon dioxide (CO₂) in data centers represent open challenges and driving the future research work for green data centers. Our Literature review reveals that there is an urgent need for integrated energy efficiency framework for data centers which combines a green IT architecture with specific activities and procedures that led to minimal impact on environment and less CO₂ emissions. The required energy efficiency framework should also consider the social network applications as a vital related factor in elevating energy consumption, as well as high potential for energy efficiency.

TABLE I. DATA CENTERS ENERGY EFFICIENCY TECHNIQUES

No	Author	Approach	Strengths	Limitation
1	Asgar Sabbaghi	Conceptual taxonomy of information technology	Supply Management	Focus on infrastructure only
2	Zhiming Wang	Maximizing resource utilization	Put into account QoS	Much job performance take amount of time Sleep-in-Waking up-ready.
3	RajkumarBuiyya	Resource allocation and scheduling	Quality-of-service	No parameter to indicate CO ₂ emission
4	Anton Beloglazov	Adaptive utilization	Meeting the Service Level Agreements (SLA)	No parameter to show the energy efficiency level
5	Meenakshi Sharma	Load balancing algorithms	Good in reduce energy, pricing and time	Much calculation need more time to take decision
6	Mueen Uddin	Virtualization	Increase the utilization ratio	High utilization leads to introduce CO ₂
7	S. Kontogiannis	workload balancing algorithm	can balance the workload in multidimensional resources	Increase the Web traffic

IV. GREEN METRICS TO MEASURE AND ASSESS ENERGY EFFICIENCY OF DATA CENTER

Globally, the energy consumption of data centers is continuously on the increase [17]. The energy operations cost will continue to double every five years between 2005 and 2025 [18]. This increase led to higher emission of CO₂ that reflects negatively on global warming and environmental health.

Measuring energy consumption of data centers has become a significant concern of all datacenters stakeholders to meet end-user agreement [19]. Energy efficiency metric is a tool used to measure energy efficiency in data centers [20]. The most important challenge in the data centers industry is the limitation of effective standard energy efficiency metrics, which supports improving energy efficiency [21,22].

For an effective energy efficiency assessment on data centers and its components, we need to assess the effectiveness of the used metrics and to measure the energy efficiency of data centers. To determine whether these metrics are effective or not we need to assess these metrics against its intended goals and under a range of common used cases to determine the values of its effectiveness in terms of reporting, targets, education, analysis and decision support [23].

Our literature review on common energy efficiency metrics that are currently in use by data centers reveals that none of these metrics are meeting the prior mentioned criteria. Therefore, our research is not only introducing a comparative review of the most common used metrics and their features (criteria) but also attempting to recommend better metric to be used in the assessment of data centers energy efficiency.

In last few years operators have adopted PUE metrics as the measure of energy efficiency for the mechanical and electrical infrastructure of the data center. The process of assessment has submitted a focus and comparable measure of performance, which has enabled data centers operators to make substantial improvements. However, until now no consensus about IT or software energy efficiency and most energy efficiency measurements stopped at the IT power cord. In this paper we are proposing the Fixed to Variable Energy Ratio (FVER) metric which could be used to measure the data centers energy efficiency instead of PUE. The reason behind our choice in favor of the FVER metric is that it combines and meets all the needed criteria for better energy efficiency assessment in data centers, listed in table 2, including the usage of IT and software applications in data centers [24]. Figure 1 depicts the difference between FVER and PUR and Table 2 represents the different Goals of energy efficiency metrics including PUE, DCiE, FVER, and DCeP where:

Power Usage Effectiveness (PUE) =

$$\text{Total Facility Power} / \text{IT Equipment Power} \tag{1}$$

$$\text{Data Center Infrastructure Effectiveness (DCiE)} = 1 / \text{PUE} \tag{2}$$

$$\text{Fixed to Variable Energy Ratio (FVER)} = 1 + \text{Fixed Energy} / \text{Variable Energy} \tag{3}$$

$$\text{Data Center Energy Productivity (DCeP)} = \text{Useful Work Produced} / \text{Total Data Center Energy Consumed over time} \tag{4}$$

V. CONCLUSION AND CONTRIBUTION

The first contribution of this paper is our literature review on current energy efficiency frameworks. The study reveals that there are currently several energy efficiency frameworks for data centers which combine a green IT architecture with specific activities and procedures that will lead to decrease the impact on environment and the diminution of CO₂ emissions. The current available frameworks have some pros and cons (see Table 1) that is why there is an urgent need for an integrated energy efficiency framework for data centers and cloud computing. The framework should consider a common and integrated set of criteria. The selection and adoption of such framework should be in accordance with the data center area of application and its surrounding environment.

The second contribution was the literature review on energy efficiency metrics that are currently used for the assessment of energy efficiency in data centers (depicted in Table 2 and Figure 2). This part of our study developed a comparative study of the most commonly used metrics and their features (criteria), additionally we recommended the use of FVER instead of PUE as a better metric for the assessment of data centers energy efficiency which was based on certain required criteria including the usage of IT and software

applications in data centers. Our future work will focus on the development and empirical validation of an integrated energy efficiency framework for cloud computing and data centers.

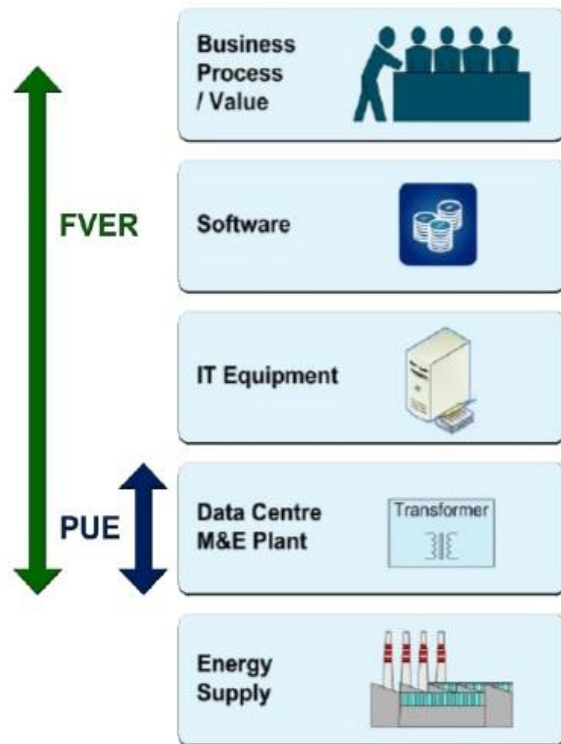


Fig. 2. FVER Vs PUE [25]

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TABLE II. GOALS OF ENERGY EFFICIENCY METRICS [24]

No	Goal	PUE	DCiE	FVER	DCeP
1	Provide a clear, preferably intuitive understanding of the measure	Y	Y	Y	
2	Provide a clear, preferably intuitive direction of improvement		Y	Y	Y
3	Describe a clearly defined part of the energy to useful work function of the IT services		Y	Y	Y
4	Be persistent, i.e. the metrics should be designed to be stable and extensible as the scope of efficiency measurement increases, rather than confusing the market with rapid replacement	Y	Y	Y	
5	Demonstrate the improvements available in a modern design of facility		Y	Y	
6	Demonstrate the improvements available through upgrade of existing facilities using more efficient M&E systems		Y	Y	
7	Provide a clear, preferably intuitive understanding of the impacts of changes			Y	Y
8	Be reversible, i.e. it should be possible to determine the energy use at the electrical input to the data center for any specified device or group of devices within the data center	Y		Y	Y
9	Be capable of supporting 'what if' analysis for IT and data center operators in determining the energy improvement and ROI for improvements and changes to either the facility or the IT equipment it houses	Y		Y	

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