AN EXHAUSTIVE FRAMEWORK FOR BETTER DATA CENTERS' ENERGY EFFICIENCY AND GREENNESS BY USING METRICS

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Abstract

As data centers become more popular today and power cost and energy consumption exponentially raised, considering energy efficiency in data centers seems imperative. To achieve more energy efficiency and greener data center, we need to define tools to measure these parameters. These tools are known as metrics, which can assess data center energy efficiency, emission level, and accordingly, its greenness. Although there are efforts have been done on data center, a comprehensive and applicable framework to accurately measure data centers' efficiency and greenness is still scarce. In this study, we explore through diverse metrics and provide a framework of best matched metrics for better and more accurate measurement of data centers' energy efficiency and greenness.

Key words: *Data center; Energy efficiency; Green metrics.*

1. Introduction

Nowadays, people have been got aware of many harmful activities which impact on their environment. The earth devastation forced government to take action against this problem and obligate organization to constrain national resources and diminish dangerous residual trash [1]. Furthermore, ICT sector must focus on optimizing energy consumption and reducing carbon emission [2]. There is a protocol which named GHG utilized as a tool for business and government to recognize, measure and control their green house gas emissions [3]. Some strategies has recommended by schulz for reforming data center energy effectiveness such as reducing consumption of power for cooling, exchange slow processor with faster one with less power consumption, and consolidate slow storage and servers to have more energy efficiency. Other studies indicated that with optimizing power, cooling and environmental requirement the outcome thrives on economics, reform energy consumption, and decrease in the carbon footprint [4].

By passing the time, due to depleting natural resource reserves, the price of energy is boosted; also demand for implementing data centres is increased dramatically. Thus, by increasing demand and cost the majors have to put energy efficiency in head of their plans for implementing and maintaining data centres. Therefore, organizations with data center have motivated to exert some energy efficiency metric; there is no clear method for applying these metrics [5]. There are many institutes, which provide metrics to measure data center greenness such as: The Green Grid [6] is a non-profit organization which cooperating to reform the resource efficiency of data centers and business computing ecosystems and the Uptime Institute comprises data centers specialist and consultants that they mainly focus on data center facilities, IT, and how both tasks can affect on cost and energy consumption of computing [7].

Accordingly, since green computing has no widely accepted metrics [8] so introducing a comprehensive metrics collection to measure both energy efficiency and greenness of data centers seem difficult. In following we will discuss some of frameworks and metrics to evaluate energy consumption and CO2 emission in data centers, but in terms of 3R concept (Reduce, Reuse, and Recycle); there still lack of a sustainable method or framework exists for the datacenters in better managing their energy consumption and CO2 emission. Moreover, while the push for data center sustainability began with a focus on energy consumption, IT leaders must recognize the critical need to address a wider range of environmental issues. By providing a clear, easily understood framework we can help data center leaders assess whether their data centers are efficient and green. In following we discuss different data center frameworks and metrics; we then introduce existing structure for data centers and categorize metrics based on both data center structure and 3R concept. Finally, we compare and determine an acceptable metrics for our framework.

2. Data Center Energy Efficiency and Greenness Frameworks

There are frameworks which have been introduced by many institutes to evaluate data center carbon emission and its energy efficiency. We list some existing frameworks in following:

2.1. Green IT Promotion Council

The Green IT Promotion Council [9] has introduced DPPE as four stage framework which we list the metrics associated with each stage as follows:

2.1.1. ITEU

The IT Equipment Utilization (ITEU) is a metric which defines the energy-saving level through implementing both virtual and operational techniques among IT equipments in a data center. ITEU indicates the average utilization of entire IT equipment within a data center, and it can be defined as below [8]:

ITEU = Total measured power of IT equipment / Total rated power of IT equipment **Eq. 1**

2.1.2. ITEE

IT Equipment Energy Efficiency (ITEE) is considered as another energy-saving metric, which can be determined by dividing the value of total capacity of IT equipment to total rated power of the IT equipment. The main approach of ITEE is to improve energy saving through setting up of new equipments with high processing capacity in terms of power consumption. ITEE can be compared by its equivalent metric (DCeP) defined by The Green Grid [9].

ITEE = Total server capacity + total storage capacity + total NW equipment capacity / Rated power of IT equipment **Eq. 2**

2.1.3. PUE

Power use effectiveness (PUE) introduces a ratio which defines a proportion of the total power is consumed by a data center to total power is consumed by data center’s IT equipment. The Equation below shows how PUE is defined [10]:

PUE = Total power going into a data center building / Power used for IT equipment ***Eq. 3***

2.1.4. GEC

The Green Energy Coefficient (GEC) determines a ratio that originated from dividing the value of Green Energy created and used in a data center by total power consumption in the data center. Since GEC is defined as a metric to persuade operators using renewable energy, so green energy outsourced from other organizations will not be considered in this metric [11].

GEC = Green Energy / DC total power consumption **Eq. 4**

2.1.5. DPPE

The Data Center Performance Per Energy (DPPE) is an integrated metric to improve energy saving in data centers. DPPE comprises four other metrics, which are ITEU, ITEE, PUE, and GEC and defined in following equation [9]:

$DPPE = ITEU \times ITEE \times 1/ PUE \times 1/1 - GEC$ **Eq. 5**

2.2. Uptime Institute

Another framework has introduced by Uptime Institute consist of four green categories as follows [12]:

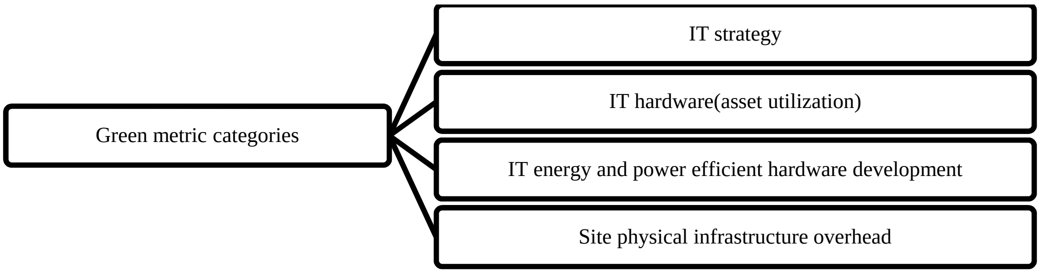

Chart 1. Uptime Institute framework for data center

The three first metric categories indicate IT hardware productivity per Watt of power consumed by IT hardware and the last one converts IT power consumption to data center utility power consumption. We listed metrics related to aforementioned framework as follows: (two first metrics related to three first categories and the two last ones define last category)

2.2.1. DH-UR

DH-UR was defined by Uptime Institute, and the main aim of this metric is to assist IT executives measuring IT equipment energy consumption when there is no application running on them. In addition, DH-UR specified e-waste reduction approaches by remove or suspend IT equipment, including servers or storage within the data center. The Institute defined following formulation for servers:

DH-UR (server)=Number of servers running live application / Total number of servers actually deployed **Eq. 6**

DH-UR (storage) = Number of terabyte of storage holding important, frequently accessed data (within at least 90 days) / Total terabyte of storage actually deployed **Eq. 7**

2.2.2. DH-UE

DH-UE is another metric introduced by Uptime Institute, which tries to assist IT managers and expertises to measure potential improvement in energy saving by utilization of server and storage through virtualization. DH-UE also reduces e-waste and defines as follows [12]:

DH-UE = Minimum number of servers necessary to handle peak compute load / Total number of servers deployed **Eq. 8**

2.2.3. SI-POM

SI-POM (Site Infrastructure Power Overhead Multiplier) defines how much power is consumed in overhead instead of critical IT equipments [13].

SI-POM= Data center power consumption at the utility meter / Total hardware AC power consumption at the plug for all IT equipment **Eq. 9**

2.2.4. H-POM

H-POM (IT Hardware Power Overhead Multiplier) can define how much of power input to hardware is wasted in power supply for fans rather than useful computing component [13].

H-POM= AC Hardware Load at the plug / DC Hardware Compute Load **Eq. 10**

2.2.5. CADE

CADE metric may be efficient in terms of characterizing data center utilization; however, it cannot be useful when basic measurement have not been calculated by data center industry. CADE is useful for executive to understand efficiency and its related operation when lack of knowledge and technical skill exists and CADE deals with high level of consumption [14].

*Corporate Average Data Efficiency = Facility Efficiency * IT Asset Efficiency* **Eq. 11**

*Facility Efficiency (FA) = Facility Energy Efficiency (%) * Facility Utilization* **Eq. 12**

*IT Asset Efficiency (AE) = IT Utilization (%) * IT Energy Efficiency (%)* **Eq. 13**

2.3. Nomura research institute

In addition, one of the leader institutes in green evaluation tools is Nomura research institute which consider following metrics:

Table 1. Nomura research institute metrics

Efficiency Metric	Formula
Asset Efficiency (AE)	Asset Efficiency (AE) = (IT Energy Efficiency) x (IT utilization)
Corporate Average Data Center Efficiency (CADE)	CADE = Facility Efficiency (FE) x Asset Efficiency (AE)
Data Center Density (DCD)	DCD = (Total CPU Cycles) / (Total Data Center Square Footage)
Data Center Infrastructure Efficiency (DCIE)	DCIE = (Total IT Equipment Power) / (Total Facility Power)
Data Center Productivity (DCP)	DCP = (Useful computing work) / (Total Facility Power)
Deployed Hardware Utilization Efficiency (DH-UE)	DH-UE = (Minimum Number of Servers Required for Peak Load) / (Total Number of Servers Deployed)
Deployed Hardware Utilization Ratio (DH-UR)	DH-UR = (Number of Servers Running Live Applications) / (Total Number of Servers Actually Deployed)
Facility Efficiency (FE)	Facility Efficiency (FE) = (Facility Energy Efficiency) x (Facility Utilization)
Power Usage Effectiveness (PUE)	PUE = (Total Facility Power) / (Total IT Equipment Power)
Storage Automation (SA)	Storage Automation = (Human Operators) / (Storage Density)
Storage Density (SD)	Storage Density = (Storage Utilization) / (Total Data Center Square Footage)
Storage Utilization (SU)	Storage Utilization = (Server, Network and Backup Storage in Use) / (Total Storage Available)

2.4. Emerson corporation

Although most of Nomura research institute's metrics are influenced by reusing or recycling of components but there are only four metrics directly focus on recycling and reusing and measure efficiency of data centers. The metrics are listed as follows:

Table 2. Recycling and Reusing metrics in data center

Metrics	Definition
The Energy Reuse Effectiveness (ERE)	• **ERE = (Cooling + Power + Lighting + IT-Reuse) / IT** **IT is the energy used by all of the IT equipment (servers, network, storage) in the data center** • **ERE = (1-ERF) × PUE**
The Energy reuse factor (ERF)	**ERF = Reuse Energy / Total Energy**
Material Recycling Ratio (MRR)	**[Total Recycled, Reclaimed, Reused Material in Mass (lbs/Kg)] / [Total In-Bound Material – Outbound Product & Service in Mass (lbs/Kg)]**
Material Reuse Effectiveness (MRE)	**[Total In-Bound Material – Outbound Product & Service in Mass (lbs/Kg)] / [Total Recycled, Reclaimed, Reused Material in Mass (lbs/Kg)]**

The two first metrics (ERE, ERF) are considered as energy reuse metrics (like heat uses to warm up a pool) and other two metrics (MRR, MRE) emphasize physical recycle and reuse of material throughout a data center [15], [13], [16].

2.5. The Green Grid

Since there has been great tendency toward evaluate and compare data centers in different perspectives, the Green Grid has developed some indicators to help visualize real-time state of the data center. In below we listed four key indicators which help multi-dimensions view of data center operation:

2.5.1. UDC: Data Center Utilization calculates the amount of power that IT equipment consumes regarding to the data center real capacity.

UDC =IT Equipment Power / Actual power capacity of the data center **Eq. 14**

2.5.2. Userver: Server Utilization measures rate of maximum ability of the processor in the highest frequency state.

Userver =Activity of the server's processor / Maximum ability in the highest frequency state **Eq. 15**

2.5.3. Ustorage: Storage Utilization defines a ratio through which percentage of used storage regarding to overall storage capacity will be measured within the data center.

Ustorage =Percent storage used / Total storage capacity of data center **Eq. 16**

2.5.4. Unetwork: Network Utilization depicts the percentage of used bandwidth over total bandwidth capacity within the data center.

Unetwork =Percent network bandwidth used / Total bandwidth capacity of data center **Eq. 17**

Referring to aforementioned indicators, they are valued between 0 to 100% which 100% consider as maximum and ideal for any business [17]**.**

2.5.5. DCIE

The data center infrastructure efficiency (DCIE) is known as another data center metric, which is a mutual metric for PUE and frequently stated as a percentage.

*DCIE= IT Equipment Power / Total Facility Power *100%* **Eq. 18**

The PUE and DCIE metrics are usually defined to identify data centers' energy consumption and act as predecessor requirements for green measurements [10]. There some implications are provided by PUE and DCiE such as: 1- Offer opportunities to develop operational efficiency in a data center; 2- Provide insights to enable data center's comparison; 3- Present tools to improve data center designs and processes gradually; 4- Opportunities to support energy for additional IT equipment [18].

The main reason that data centers must collect information to measure DCiE is because it provides valuable tools, which help IT managers to evaluate their data center with another data center. In addition, DCiE enables IT managers to identify the effectiveness of any changes made within a given data center. DCiE also defines the amount of power is consumed by the facility infrastructure due to accurate power distribution among IT equipment, supply sufficient cooling for IT equipment and deliver sustainable power to the IT equipment [19].

2.5.6. DCPE

Data center Performance Efficiency (DCPE) explains the efficiency of data center in terms of power consumption when a specific level of service or work is given [20]. This metric was proposed by The Green Grid which is basically built from expansion of PUE and DCE.

DCPE= Useful Work / Total Facility Power **Eq. 19**

Determining DCPE is much more complicated because it is emerging over time and the Green Grid believes that it can be a key strategic factor for government and industries [21].

2.5.7. DCD

Most of organizations have been seeking approaches to measure performance of their IT equipments in data centers. The data center density (DCD) has introduced to assess the performance-per-watt of the data centers, and their components based on the short-term basis. DCD focus on a tactical part of data center design, including IT operational efficiency, IT service level agreement, and implementing technologies. The equation shows how DCD is calculated [22]:

DCD= Power of All Equipment on Raised Floor / Area of Raised Floor **Eq. 20**

2.5.8. CUE

Since the data center sustainability plays significant role in the organization, the Green Grid tries to fill the gap by introducing new metrics for measuring sustainability of data centers. In fact, introducing such metrics can assist organizations to recognize whether their current data centers are efficient before they decide to implement a new data center. Thus, the Green Grid proposed new metric called carbon usage effectiveness (CUE) which measures carbon emissions of data centers [23].

CUE= Total CO2 emission caused by the total data center energy / IT Equipment Energy **Eq. 21**

2.5.9. DCeP

To identify an inclusive efficiency measurement in a data center we must consider productivity of the data center which is useful work of IT equipment [24]. Thus, the Green Grid has introduced a new metric called Data Center energy Productivity (DCeP) which is able to measure both site infrastructure and the IT equipment while assessing data center energy efficiency. The DCeP is the first metric in DCxP family and can be estimated as follows [25]:

DCeP = Useful work produced in a data center / Total energy consumed in the data center to produce that work **Eq. 22**

2.5.10. CPE

TGG has introduced an interim metric or proxy for productivity to allow data centers today to estimate their productivity as a function of power used named Compute Power Efficiency.

Although the introduction of DCeP can help better estimation of data center productivity, there are still gaps in this area. In terms of fill up this gap, many discussions have been done, and interim metrics (or “proxy”) has been introduced to measure productivity of data centers as a function of power used. The Compute Power Efficiency (CPE) is an example of this proxy metrics and can be calculated as follows [17]:

CPE = IT Equipment Utilization / PUE **Eq. 23**

or

*CPE = (IT Equipment Utilization * IT Equipment Power) / Total Facility Power* **Eq. 24**

2.5.11. ScE and DCcE

Most of the metrics have been introduced to determine productivity for data centers need to define usefulness of work is being performed. Thus, two metrics has been introduced filling this gap.

Server compute efficiency (**ScE**) offers a technique to measure efficiency of servers in data centers which can help managers to improve total energy use. By this method managers can determine servers which are not providing primary services for specific periods, and can switch off, decommission, or virtual those servers. The reduction regarding to applying these techniques have effect on the power consumption related to data center infrastructure.

The **DCcE** metric offers a track system which enables data center operator to calculate efficiency of computing in servers during specific time and decide right population size for servers referring the job at hand. Based on this metric we are able to determine the right amount of power and cooling infrastructure to support the necessary load, which finally lead to power usage effectiveness (PUE) optimization [26].

3. Data centers structure

Before we are able to build a prototype for our framework we need to understand data center. Surely the outcome of data center is not tangible, as result modeling data center seems to be essential [27]. Various data center have been implemented in different organizations and each organization considered different elements and factors in their modeling and design. These factors can comprise proportionality of area or facilities or equipment which may be the source of discrepancy among data centers. Here, we concentrate on the facility infrastructure and IT equipment as two main parts of data centers. In following the holistic data center model was depicted.

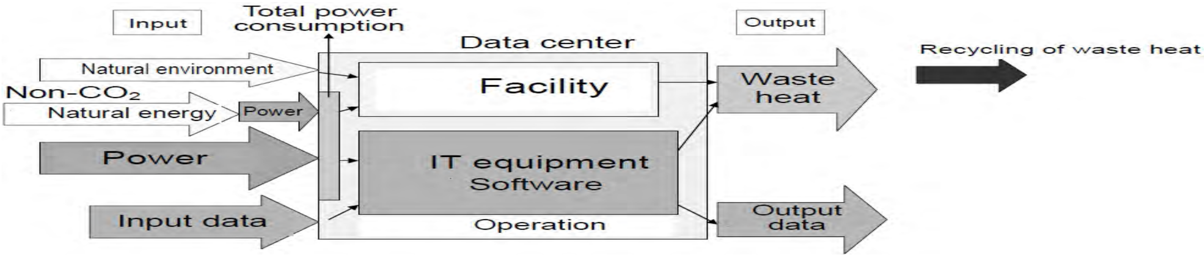

Figure 1. Data center structure

The up side figure depicts a data center in two different segments. The first segment refers to devices for constructing huge IT project such as a powerful air conditioning or power supply system, including power substation and amplifier or rectifier. The second segment refers to how these equipments work and how they are functioning. For each section electricity power needed for data processing, so electrical energy play important role in data centers. The classification of electrical energy derived into two categories: grid power and green power transformer. In this concept as mass amount of energy has been wasted during the process, thus recycling heat energy result from the process is a particular part of this model [9].

We mentioned facility infrastructure and IT equipment as main parts of a data center; therefore, we need to understand a whole picture of both parts to evaluate data center greenness. The body of literature [13] stated following picture:

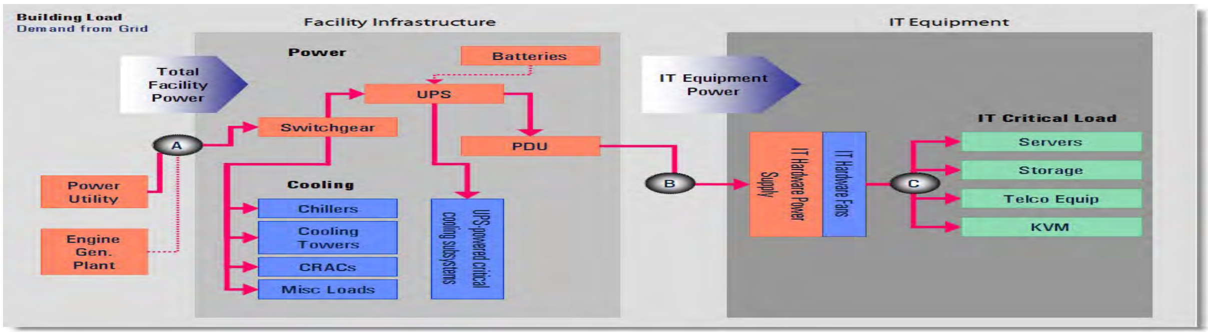

Figure 2. Data center sub-system

Figure 2 basically focus on electricity power current from major components of data center like power system cooling and computing system and also flow from some power measurement point.

4. Metrics categorization

Once presenting the most useful and applicable metric in data centres and drawing the model in data centre structure; we divided each system into two key data centre subsystems as IT equipment and site infrastructure. Each metric potentially can assess either one or both data centre subsystem. Thus, those metrics which can evaluate both data centre subsystem illustrate more implication about effectiveness of energy consumption in data centre but they cannot reveal capabilities of other sections. In following table we categorize metrics based on two data center subsystems:

Table 3. Metric categorization based on data center sub-system

	Data Center Subsystem	
Metrics	**IT Equipment**	**Site Infrastructure**
PUE		√
DCPE	√	√
DCD	√	
CUE	√	
DCeP	√	√
CPE	√	√
DH-UR	√	
DH-UE	√	
ITEU	√	
ITEE	√	
GEC		√

DPPE	√	√
DCiE	√	√
SI-POM		√
H-POM		√
UDC	√	
Userver	√	
Ustorage	√	
Unetwork	√	
ScE and DCcE	√	√
CADE,FE,AE	√	√
ERE		√
ERF		√
MRR		√
MRE		√
SA, SD, SU		√

Now in table 4 we categorized each metric in terms of measurement of data center reduce, reuse, and recycle perspective.

Table 4. Metric categorization based on type of measurement

Metrics	Reduce	Reuse	Recycle
MRR, MRE		√	√
ERE		√	√
ERF =Reuse Energy/Total Energy		√	√
PUE, DCIE, CPE,DCD(Data Center Density), UDC(Data Center Utilization), CUE, DCPE, Userver, Ustorage, Unetwork	√		
SA,SD,SU	√		
DH-UE	√		
DH-UR	√		
CADE,FE,AE	√		
DCeP	√		
SI-POM, H-POM	√		
ITEU, ITEE, GEC, DPPE	√		

5. Metrics comparison and framework

Since we had sufficient information about each part of data center that can be measured by each metric and also know the relationship of each metrics with 3R concepts, so we conducted comparison as follows:

	Data Center Subsystem		**Three R concepts**			**Comment**
Metrics	**IT Equipment**	**Site Infrastructure**	**Reduce**	**Reuse**	**Recycle**	**Accept/Reject**
PUE		√	√			*Accept*
DCPE	√	√	√			*Accept-expansion of PUE and DCE to explain efficiency of DC in power consumption*
DCD	√		√			*Reject*
CUE	√		√			*Accept-measure carbon emission of DC*
DCeP	√	√	√			*Evaluate better than ITEE-Accept*
CPE	√	√	√			*Reject since there ScE and DCcE are better metrics*
DH-UR	√					*Accept- complete each other to evaluate both part of data center in terms of Reduce.*
DH-UE	√					
SI-POM		√				

H-POM		√				
ITEU	√					*Accept*
ITEE	√					*Accept due to calculate DPPE*
GEC		√				*Accept due to green energy calculation*
DPPE	√	√				*Accept*
DCiE	√	√	√			*Accept- compatible with PUE*
UDC	√		√			*Accept because they are indicators to help visualize real-time state of the data center*
Userver	√		√			
Ustorage	√		√			
Unetwork	√		√			
ScE and DCcE	√	√	√			*Accept-define power consumption efficiency of DC over time*
CADE,FE,AE	√	√	√			*Reject because difficult to perform.*
ERE		√		√	√	*Accept because they focus on reuse and recycle in data center site infrastructure*
ERF		√		√	√	
MRR		√		√	√	
MRE		√		√	√	
SA, SD, SU		√	√			*Reject-there are better metrics*

Table 5. Metrics comparison

Based on table 5 above we rejected some metrics due to disability to evaluate both data centers sub-systems and existence of more powerful metrics which can cover the gaps to avoid overlapping in measurement of data center energy efficiency and greenness. Our propose framework is as follows:

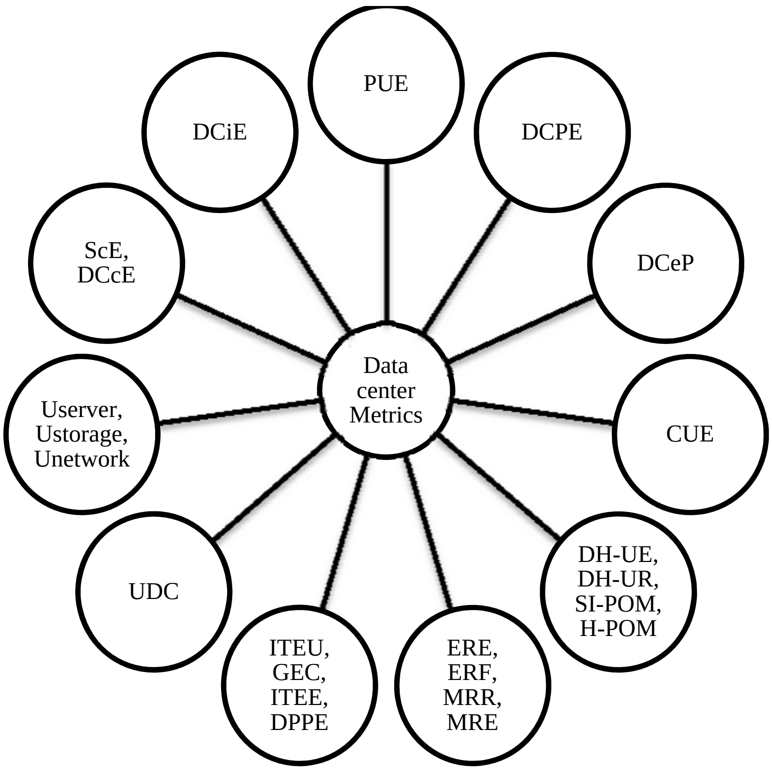

Chart 2. Metric Framework

6. Conclusion

In this study, we seek to have an overview on existing data center frameworks and metrics to introduce a holistic framework for better measurement of data centers energy efficiency and greenness. We first investigate through existing frameworks such as the Green Grid, Uptime institute, and Green IT Promotion Council and their respective green metrics. To understand and categorize the overviewed metrics we needed to have insight about data center structure, therefore we explore the original data center framework. Nevertheless, we only concentrate on two subsystems of data center, which are facility infrastructure and IT equipment. In the next step, we categorize and rearrange metrics based on data center structure and determine the role of each metric inline with reduce, reuse, and recycle form of measurement in data center. Accordingly, we exert hand to hand metrics comparison and define accepted and applicable metrics for our framework. To avoid over lapping of metrics we eliminate some metrics which can result more accurate measurement of data center energy efficiency and greenness. Our framework will help government and business owners especially data center owners to improve energy efficiency and greenness of data centers.\

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