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Green IT – Data Center Efficiency Assessment

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ABSTRACT

Technology has become a vital element for all organizations and this growing significance has forced companies to have huge and solid IT structures. However, today IT developed into one of the biggest contributors to the global warming. Both for environmental and financial motives and to remain competitive, companies need to ensure that their information technology systems are managed in an environmentally friendly manner.

In order to manage the IT systems adequately, all the elements of the system should be deeply and correctly evaluated and inefficiencies should be clearly determined. Metrics are extremely vital for this evaluation.

This study aims to understand the role of Datacenters within the field of Green IT. They account for the most of the energy consumption within the IT facility, and have therefore a major impact on environment and costs. In this connection this paper will answer two main questions. First, which metrics need to be assessed to rate the efficiency of a Datacenter both qualitatively and quantitatively. Second, which are the most suitable tools to gather and process the necessary data for the metrics calculation. Eventually theoretical findings will be compared and analyzed with the industries best practices.

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Introduction

1.1 Motivation

The planet is warming, from North Pole to South Pole, and everywhere in between. Global warming has become a major concern of humanity since the middle of the 20th century. It is believed to increase each year, hence, the increase in the average temperature of the Earth's near-surface air and oceans will continue. According to the scientists, the society causes irreversible harm to the planet by burning fossil fuels and cutting down trees, which makes global warming environmentally unsustainable.

The unpredictable climate change due to rising Greenhouse emissions will have significant economic and social implications on a global scale, which has forced governments to act rapidly. Governments have set legislations on a global scale requiring organizations to be accountable for their energy consumption, Greenhouse emissions and carbon footprint on the environment. Energy consumption is gradually gaining more importance on an organization's reputation and corporate image. It is possible to have clean, renewable and Green energy sources for energy consumption. Since these Green energy sources are still expensive, it becomes unfeasible even for the main energy consumers to use renewable energy. Hence sooner or later reducing energy consumption will become an environmental necessity, as well as an economic need.Taking all these into account, it is becoming more and more important for all businesses to act in an environmentally responsible manner. That is not only to fulfill their legal and ethical obligations, but also to develop a healthier brand and to improve their corporate image, which helps companies to compete in a Green market and also to increase their shares.

Hence, also for Datacenters this trend has a significant impact, since they have a major stake on the worlds CO_2 emissions, by consuming an extraordinary amount of energy. They are rapidly growing in number and size due to various evolvements in the last decade, i.e. web 2.0 applications. That means that there is a cogent urge to improve energy efficiency within Datacenters, to thwart shooting up of costs andkeeping clean with corporate responsibility.

Consequently there is a huge informational demand on Green IT topics that show up how energy efficiency can be assessed and achieved respectively. This paper meets this need by giving first a general description of Green IT and its importance in today's businesses. Being the matter of consideration, also all Datacenter facility components will be presented shortly. Afterwards relevant indicators for Data Center assessment are being gathered, properly analyzed and evaluated. They are commonly referred to as metrics and they represent the analytical formula behind every Datacenter assessment. Naturally they were useless if not being handled the right way. Hence, adequate software tools are crucial for monitoring and calculating the metrics. The tools are presented and evaluated in terms of suitability to calculate specific metrics. To support theoretical findings properly, in the last part of this paper direct contacts to companies of relevance were established to collect best practices in the above-mentioned topics.

The evaluation was made to the best of the authors knowledge. It is based on professional books and papers, as well as voices of the industry, and thereafter interpreted and extended by the authors' personal knowledge.

1.2 Environmental Issues

Global warming is caused by Greenhouse gases, mainly carbon dioxide (CO_2) and methane (CH_4), which prevent heat from escaping the earth. The studies have shown that as a result of the global warming activities taking place, far more CO_2 is pumped into the atmosphere than was ever released in hundreds of thousands of years. This increase of CO_2 is the main reason of global warming. Though natural amounts of CO_2 have varied from 180 to 300 parts per million (ppm), today's CO_2 levels are around 390 ppm. That's 25% more than the highest natural levels over the past 650,000 years. Increased CO_2 levels have contributed to periods of higher average temperatures throughout that long record.

1.3 Impact of Green IT

Green IT refers to the environmentally sound use of Information Technology. Information Technology (IT) is at the heart of every successful modern business. Yet the deployment of Information Technology has caused various side effects i.e. the emission of Greenhouse gases. Presently Information and Technology (IT) accounts for about 2% of total Greenhouse emissions worldwide and this will increase substantially over the next 10-15 years as the adoption of IT increases exponentially in developing countries. As a result organizations directly or indirectly will need to reduce their energy consumption and Greenhouse emissions.

As figure 1 shows, the IT department is not always the greatest contributor of carbon emission within the organization. Service organizations cause significant environmental IT impacts relative to their total environmental footprint. However, The Information Technology (IT) industry has a critical role to play in ensuring a reduction in energy consumption of corporate and particularly office computing where thousands of PCs and laptops are deployed currently without much thought given to energy consumption and recycling or disposal.

Hence for every organization, IT has an impact sufficient enough to pay attention for reducing its environmental damage. Considering the anticipated increase in energy costs and the current debate on climate change, Green IT is very relevant for society. However it is beyond doubt that the challenge cannot be met by those responsible of IT alone. Instead, there is a mission for corporate and government strategists to make available the new potential from reducing of energy consumption from economic growth.

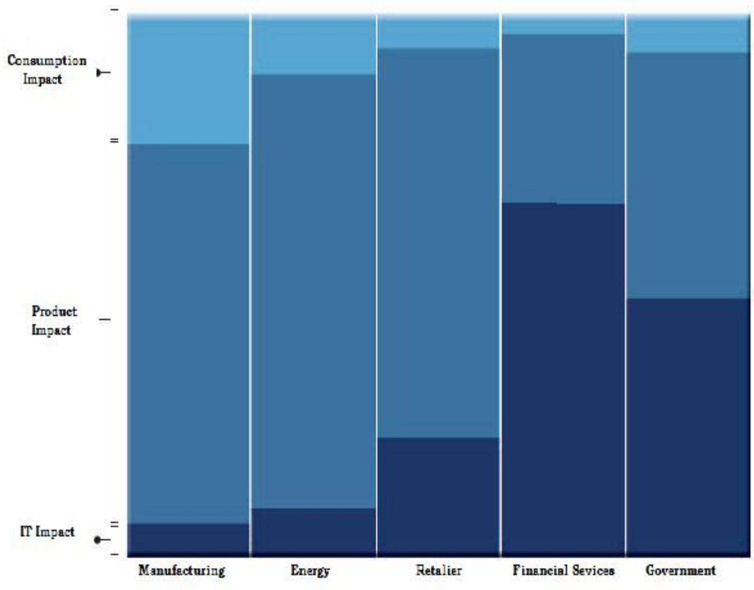

Figure1 Impact of Consumption

The elements of IT systems, which have significant impact on the environment, are computers and Data Centers. Currently PCs contribute 40 % to total IT Greenhouse gas emissions attributed through power consumption. Furthermore the power consumption of servers in Data Centers has been estimated to be in the order of 23% of total power consumption and contribution to total IT Greenhouse emissions.[1]

How IT Can Help

IT can make possible Greenhouse emissions reductions through;

- Standardized reporting on energy consumption and Greenhouse emissions across industry sectors.
- Monitoring of energy use.
- Accountability of energy consumption and Greenhouse emissions.
- Enabling energy efficient innovations.
- Enabling rethinking and transformation of current practices, which are energy inefficient at the organizational and individual level through automation, behavioral change and developing alternatives to high carbon activities.
- More effective integration of renewable and distributed energy sources into the distribution network by using IT.

1.4 Benefits of Green IT

The greatest benefit of applying Green IT strategies to all industries and each company is reduced environmental impact. These include reduced carbon print, GHGs and toxic waste and easier global reporting. Green IT strategy also enables the reduction of costs related to the energy consumption, which is crucial for all companies. It also produces competitive benefits by refreshing the hardware and software every three to four years by increasingly energy-efficient technology, such as virtual servers, virtual networks, and virtual data storage. In addition, employing Green IT strategies optimizes Data Center's footprint, which again has economic benefits for companies. Also there are social benefits such as improvement in quality of life issues.

Another recently emerging benefit of Green IT strategies is that they can be used as a marketing strategy, which is called "Green Branding". Going Green employs one of the basic colours of the world to symbolize policies and procedures that help to trim down negative effects on the environment. For the companies, having a Green IT will provide a more efficient operation by controlling the energy use and will also create a green brand that attracts consumers. With the growing popularity of green branding, vendors have started to put green labels on their products and consumers also search for green products instead of the traditional ones. So now, going green also represents manufacturing sustainable and green products.

1.5 Barriers to Adopt

New solutions and opportunities for improving the energy efficiency and productivity are searched and adaptation of new technologies is discussed at all industries. However, usually short-term revenue generating technologies are preferred over the technologies that support energy use and infrastructure that result in long-term payoff periods. Because Green initiatives are perceived as efforts that will generate added costs, not concrete business benefits.

The other barriers to adopt Green IT include Organizational issues in addressing need for Green IT, Possibility of changes in the future regulations, Overall motivation level of the executives to move to Green IT, Evaluation of product end of life and asset disposal, procurement policies, and supply-chain issues

Another issue that definitely is not in favor of greening the IT is "Greenwashing" which is a term used to describe the practice of companies dishonestly spinning their products and policies as environmentally friendly, such as by presenting cost cuts as reductions in use of resources. It is a deceptive use of Green PR or Green marketing.

2 Data Centers

2.1 Data Center

Definition of the Data Center

A Data Center is defined as a central store, either physical or virtual, for the storage, management, and distribution of data and information organized around a particular body of knowledge or pertaining to a particular business.

The Motivation to green the Data Centers

Data Centers have become very essential to the functioning of business, communications, academic, and governmental systems. Data Centers have been growing and expanding quickly as our economy continues to shift from paper-based to digital information management.In the last decades, with the increasing demand to the data processing and storage in almost all of the sectors such as financial services, governmental institutions, health services, educational institutions, high-tech desired sectors the use of datacenters has increased very much. According to the Report to Congress on Server and Data Center Energy Efficiency Public Law 109-431, which was prepared by US Environmental Protection Agency in 2007, the reasons for the increased use of Data Centers are

- The increased use of electronic transactions in financial services, such as on-line banking and electronic trading.
- The growing use of internet communication and entertainment.
- The shift to electronic medical records for healthcare.
- The growth in global commerce and services.
- The adoption of satellite navigation and electronic shipment tracking in transportation.
- Use of the internet to publish government information.
- Information security and national security.

Because of the various reasons stated above for using datacenter the side effects it has caused are increased energy costs for business and government, increased emissions including greenhouse gases from electricity generation, increased strain on the existing power grid to meet the increased electricity demand, increased capital costs for expansion of data center capacity and construction of new data centers.

This rapid spread of the datacenters made it very crucial to focus on the efficient use of them. The Natural Edge Project claims that in Australia, the data centers are responsible with 0.11-0.50% of all greenhouse gas emissions around the country.The U.S. EPA's 2007 "Report to Congress on Server and Data Center Energy Efficiency" estimated that the energy use of the nation's servers and data centers has doubled from 2000 to 2006 to approximately 61 billion KWH. If this trend continues, national energy consumption by servers and data centers is expected to be 100 billion KWH by 2011.Hence possibly the Greenhouse gas emission is also expected to increase causing serious environmental impact.

Due to the increased importance of environmental safety, nowadays governments offer green incentives: monetary support for the creation and maintenance of ecologically responsible technologies. Server refresh is one such technology, which offers data centers a convenient opportunity to go green and also is very economical.

Table1, which is derived from US Environmental Protection Agency's report show the rate of each unit's consumption according to overall energy consumption of a datacenter.

End Use Computer	**2000**		**2006**		**2000-2006**
	Electricity use(billion kWh)	**%Total**	**Electricity use(billion kWh)**	**%Total**	**Electricity use CAGR**
Site infrastructure	14.1	**50%**	30.7	**50%**	14%
Network Equipment	1.4	**5%**	3.0	**5%**	14%
Storage	1.1	**4%**	3.2	**5%**	20%
High-end servers	1.1	**4%**	1.5	**2%**	5%
Mid-range servers	2.5	**9%**	22	**4%**	-2%
Volume servers	8.0	**29%**	20.9	**34%**	17%
Total	**28.2**		**61.4**		**14%**

Table1 Energy Consumption Amounts of Each Unit in a Data Center

Green energy efficient data centers can help us reduce greenhouse gases, which, in turn, can help reduce global warming. The recent UN and White House sessions on climate change emphasize the environmental importance of green projects. Although the extent of the global warming danger might continue to be open to debate, implementing green data centers presents a significant opportunity for all of us to help reduce greenhouse gasses. As seen in the table, the cooling process takes an important role in the overall energy consumption of data centers by 50% rate. Likewise, the servers with power supply units in total take the 40% of the consumed energy. Although the energy consumption rate of the network equipment and storage units are relatively low, they consume around 3 billion kWh electricity. Therefore, as a cost saving measure, as a marketing strategy or due to an environmental consciousness; it is very crucial for each entity to make all the elements of data centers greener.[2]

The Sub-Parts of the Data Center

A Data Center is consisted of servers, data storage devices, power supply units, networking equipments and the cooling units and as a result of the fact that each unit in a data center consumes a very high amount of electricity, and causes big charges both on economy and the environment, there is a need to create opportunities to increase their efficiencies and decrease these effects. The possible efficiency increasing methods for each sub unit of a data center is analyzed.

2.2 Servers

A server is a combination of hardware and software that provides a service to the client software and computers. In the current technology, there are two types of servers which are rack-mount servers and blade servers. The rack-mount server is the type in which the server is located in a horizontal box 1.75" high and mounted on the 19" or 24" width racks. In this kind of servers the number of server units that can be mounted on a rack together is limited with 42 units of servers. On the other hand, blade servers are formed by multiple electronic circuits that are housed in one blade chassis and there is not such a limitation of the servers that are combined together and with the current technology 128 discrete servers can be achieved.

When comparing the two types of servers we could find that blade server offers more advantages than that of rack mounted server. There is improved power utilization, more flexibility, Lower acquisition costs, Lower operational costs for deployment, troubleshooting and repair, reduced cabling requirements and Lower power, cooling, and space requirements.

In the following paragraph we would discuss about some specific techniques such as energy-proportionality designs and virtualization for choosing the server type with higher server efficiency.

Energy Proportionality Designs

Energy proportionality is a principal to ensure that energy consumption is proportional to the system workload. According to Barosso and Hölzle, Energy-proportional designs in servers would enable large energy savings thus doubling their efficiency in real-life use. To achieve energy proportionality it is very important that we improve the energy usage profile of every system component, particularly the memory and disk subsystems

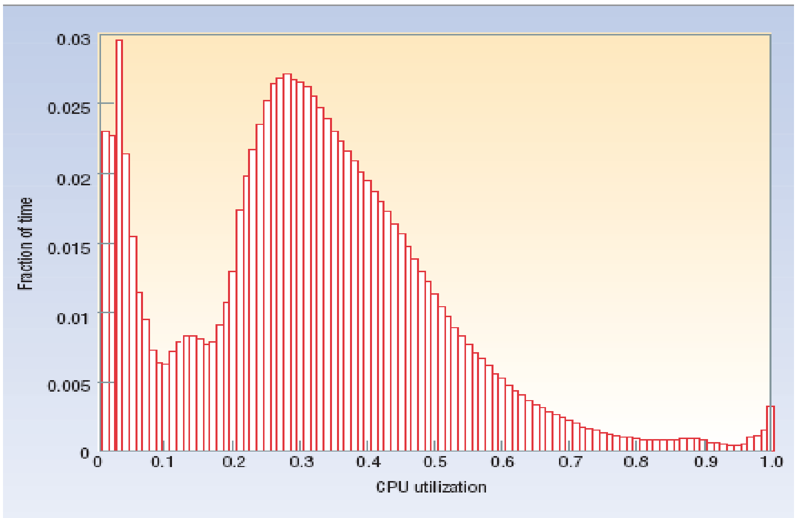

Figure2 Server Utilization

Figure 2 shows the CPU utilization levels for thousands of servers during a six-month interval. It could be observed that servers are rarely completely idle and they are rarely utilized to its maximum utilization limit. They are generally operated between 10% to 50% utilization rates.

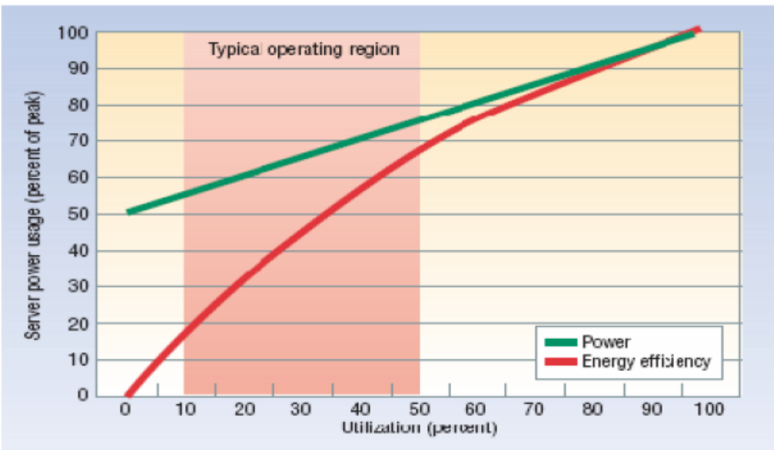

Figure3 Power Usage and Energy Efficiency with respect to Utilization of Standard Servers

From figure 3 it could be observed that even an energy efficient server still consumes about half its full power when doing virtually no work. We could also notice that peak energy efficiency occurs at peak utilization and drops quickly as utilization decreases. The servers usually work in the utilization rate of around 30% and rarely work in peak or totally idle utilization. As a result of this, it is not possible to come with a solution to stand-by the servers, which are idle since they are very rarely in a total idle mode and there is a necessity of high penalty power to wake-up the server. Also, since the data is distributed to almost all of the servers in order to increase the service level and because of security reasons (a protection of data against a break down in one server), making some of the servers in the data center idle cannot be done. Therefore, there is a need to come with a solution to increase the power efficiency of server that considers the utilization levels and energy efficiencies with respect to the utilization levels.

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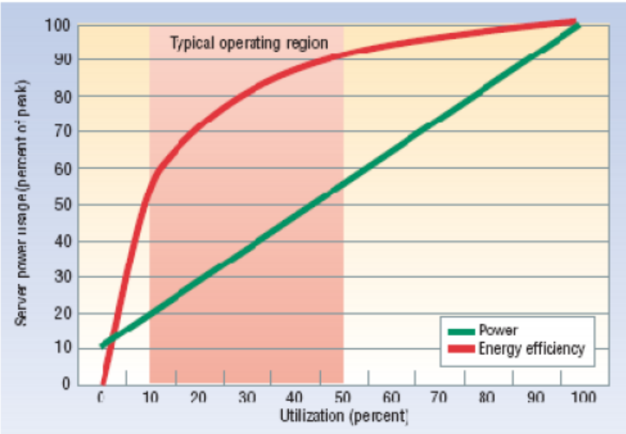

Figure4 Power Usage and Energy Efficiency w.r.t Utilization

The typical operation region of the servers is between the utilization level of 10% and 50% and the energy efficiency of the servers in this range is not in a desired level. The energy efficiency is at highest level in the peak usage of the servers and decreases dramatically when the utilization level reduces. The efficiency is between 20% and 70% in the typical operating region. Using the energy proportionally designed servers would bring a profound advantage in term of energy efficiency and power consumption because these servers use much less power in the typical operating range and as a result of this the energy efficiency will increase dramatically. The major innovation of these kinds of servers is that they consume no power in totally idle mode, very low power in low utilization levels and higher power in the peak levels. Barosso and Hölzle indicate that the energy proportional servers increase the energy efficiency in the typical operation range up to 60%-90% and decrease the power consumption to the half values in this range

	Utilization-10		Utilization-30		Utilization-50		Utilization-75		Utilization-100	
	E.E	P.C	E.E	P.C	E.E	P.C	E.E	P.C	E.E	P.C
Standard Servers	10	50	40	60	70	60	85	80	100	100
Energy-Proportional Servers	50	20	75	30	90	50	98	70	100	100

Table2 Comparison of Standard Servers and Energy-Proportional Servers

Table2 shows that the energy-proportional servers bring an overwhelming dominance to standard servers in terms of energy efficiency (E.E) and the power consumption (P.C) especially in the utilization level range of 10%-50% which is the typical operating range of the servers.[3]

Virtualization and Consolidation

Consolidation of the servers is another strategy in addition to the energy-proportional design strategy that will help to increase the energy efficiency and save power. As stated in energy-proportional design of devices section, the servers work in low utilization rates and they are mainly in idle mode and these servers consume very high power(50% of the peak power in 10% utilization for standard servers) even when they are idle. According to the VMWARE white paper, x86 hardware is the most significant cause for power consumption in data centers. Also X86 servers typically house only a single application, and their processors sit idle 85%-95% of the time. While sitting idle, these servers use nearly as much power as they do when they are active. According to analysts, companies maintain roughly three years of excess hardware capacity due to this vast underutilization. With more than seven million servers sold annually, this represents more than 20 million servers sitting idle and wasting energy. This inefficiency is not only wasteful but expensive, especially as electricity costs and computing demand continue to rise.

An action against this wastefulness is to consolidate some servers in a data centers. With consolidation, a server starts to do multiple works instead of only one work. This process might increase the utilization of the servers to 70%-80%. Thus the no of physical servers in operation get reduced resulting in an energy consumption decrease of 80%and as a result the energy efficiency of the server will be raised. In addition to this savings, another advantage that virtualization brings is flexibility. By virtualization, the data centers will easily and rapidly be adapted to business need changes thanks to distributed resource management.

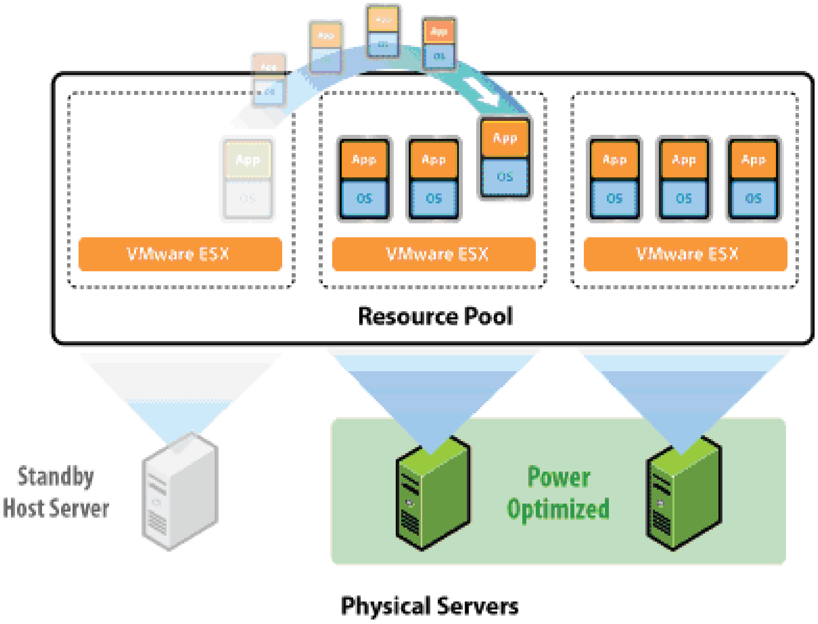

Figure5 Distributed Resource Management

As seen in the schematic of distributed resource management, the work load of a server is set to another server that works with low utilization. This will create a gain in the efficiency of the newly assigned server while the other server remains totally idle and can be kept in standby. Also, when there is a business requirement change in terms of data processing, the totally idle server will rapidly give service. The effects of virtualization are cited by VMWARE white paper: Every server that is virtualized saves 7,000 kWh of electricity and four tons of carbon dioxide emissions per year. With more than a million workloads running on VMware Infrastructure, the aggregate power savings are about 8 billion kWh, which is more than the heating, ventilation and cooling electricity consumed in New England in a year. If companies have an average of three years excess capacity as analysts suggest, this represents a reduction of 80 million tons of carbon dioxide emissions per year, which is equal to the emissions of half of all countries in Latin America.[4]

2.3 Data Storage Devices

These devices are used in order to stock the data and there are two types of data storage devices used in data centers

Storage Memory

There are two drives commonly used as storage memory which are hard disk drive (HDD) and solid state drive (SSD). However, it appears that SSDs take place of HHDs soon, when compared SSDs and HDDs, it is obvious that SSDs power consumption is less than HDDs during operation, besides SSDs are faster, more reliable and have a longer operating life. The main shortcomings of SSDs, as of mid-2008, are that they have lower capacity and they are more costly.

Power consumption of hard drives is affected mainly by design of the hard drive's spindle motor and the number and size of the spindle platters and, also, other components such as the actuator and controller board. The first available opportunity to save energy from data storage units is also consolidation. It is possible to use higher capacity drives instead of multiple lower capacity drives and this will create power reduction. Other advantages due to data storage unit consolidations are easy manageability, higher storage utilization and better performance.

In addition to consolidation and higher capacity drives usage, different technologies of storage units provide different amount of power consumption. As an example, serial advanced technology attachment drives (SATA) consume almost half power per TB of equal capacity Fibre-Channel drives.

2.4 Power Delivery components

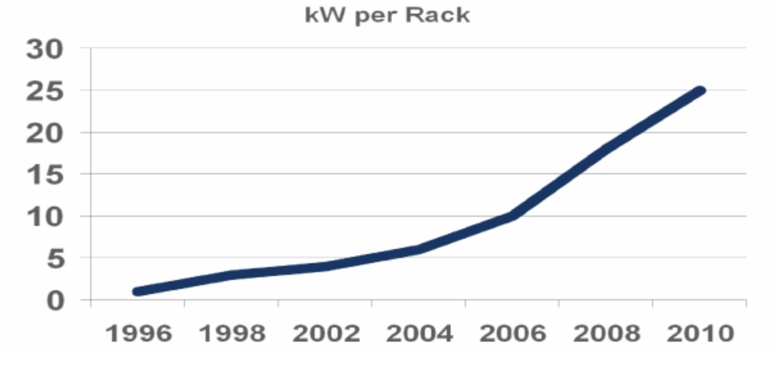

Figure 6 Rising Energy Consumption in the Data center

From figure 6 it could be noticed that there has been a continuous increase in energy consumption every year. Hence the basic components UPS, PDU and server power supply units have to be improved.[4]

Improved AC Power Distribution schemes

480V-208V Power Distribution (Present Day)

The present day 480V-208V uses the highest efficiency components on the market today. The overall efficiency, depending on the load ranges between 80%-85%.

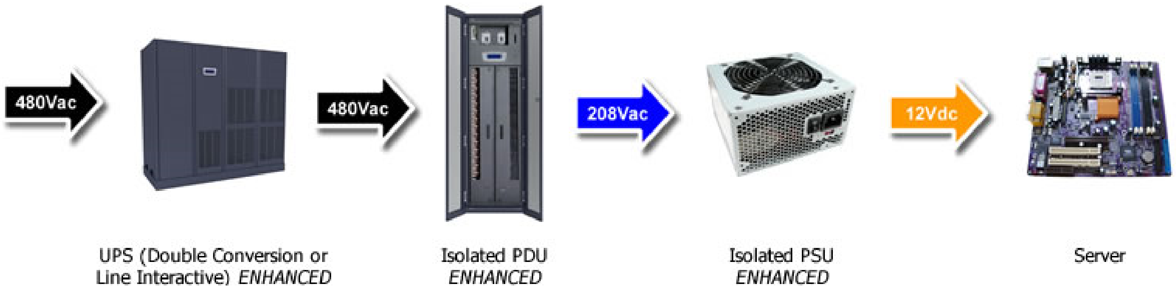

Figure 7480V-208V Power Distribution scheme

600V-208V Power Distribution

It is similar to480V-208V Power Distribution the only difference is the higher input voltage into the UPS. The overall efficiency of the design ranges also between 80%-85%.

480V/277V Power Distribution

This power scheme distributes electricity in a three-phase configuration; the voltage remains constant through the PDU, improving the efficiency of design. This power distribution scheme achieves efficiencies between 85%-90% .

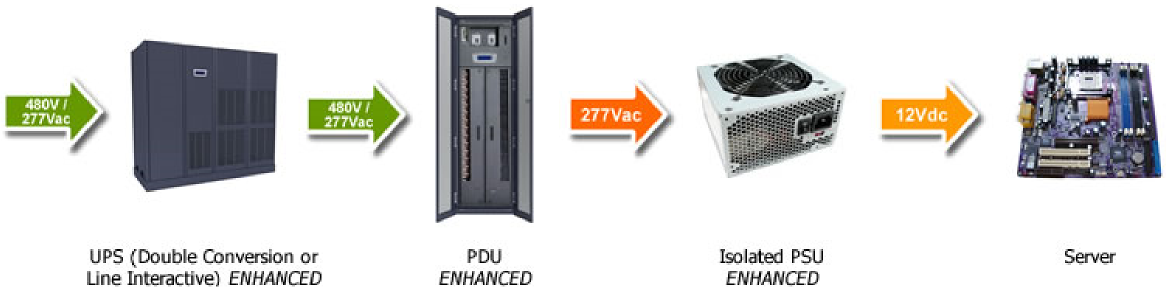

Figure 8480V/277V Power Distribution scheme

DC Power Distribution schemes

There are multiple points, including the UPS and server power supplies, at which the incoming AC power is converted to DC. Losses occur during each conversion. Hence DC power distribution method is a way to minimize electrical losses, thus achieving a more efficient design.

480Vac to 48Vdc Power Distribution

The 48Vdc power distribution design is most common in telecom deployments. It achieves efficiencies of 85%-90% based on the load.

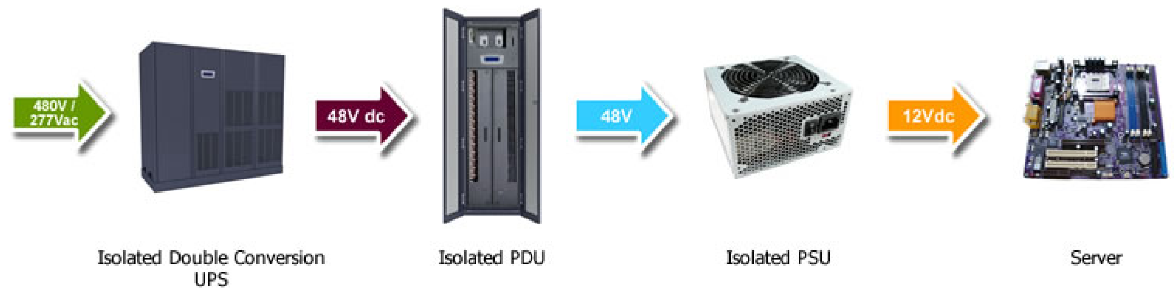

Figure 9 480Vto 484V dc Power Distribution scheme

480Vac-575Vdc-48Vdc Power Distribution

This design distributes 575Vdc power from the UPS to minimize distribution cabling losses and cost. The efficiency levels, ranges from 80% to 85% depending on the load.

480Vac-380Vdc Power Distribution

This design distributes 380Vdc to the server power supply, achieving greater efficiency and minimizing losses in the distribution cabling. It achieves 90% at 30%-50% of capacity with the overall efficiency decreasing slightly as the load nears full capacity.[5]

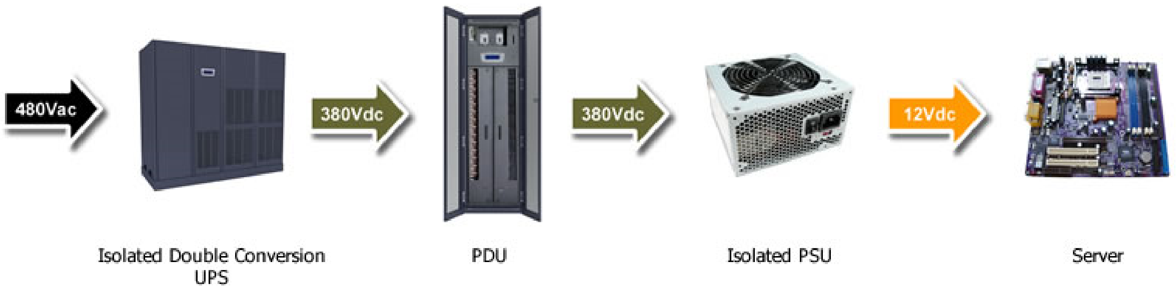

Figure 10 480Vto 484V dc Power Distribution scheme

Components of the power supply scheme for Datacenter

PDU - Power Distribution Unit

The main function of a power distribution unit (PDU) is to house circuit breakers that are used to create multiple branch circuits from a single feeder circuit. A secondary function of some PDUs is to convert voltage.

UPS – The Uninterruptible Power Supply

The uninterruptible power supply (UPS) converts unconditioned power to provide conditioned power to critical loads. It contains an energy storage system, such as batteries, that can supply power to the load. The varieties of UPS system available are standby, line interactive, stand by fero, double conversion online, delta conversion online. The choice of the correct UPS type depends upon the efficiency, reliability and other design attributes. The double-conversion batteries are still the main back-up power supply units for data centers.

PSU- Power Supply Unit

The power supply unit (PSU) converts an input voltage to a regulated 12Vdc output voltage. Power supplies units are designed to power a single server chassis as part of a redundant configuration. They must have an EMI filter, input reverse current protection, sufficient capacitance to provide adequate hold up time and output ORing circuitry.

2.5 Network Equipments

The network equipments in a data center are the connection elements between servers, computers and all other devices used in data centers.

Although the power consumption of the network equipments occupies only 5% of the overall data center power consumption, still there are some opportunities about them that might be created to decrease the used power, and make the data center more economic and environment-friendly. The energy need of the networking increases rapidly because of the higher and more complex data traffic and the need to make this data flow with better performance, reliability, security and flexibility. Therefore, in order to overcome this high energy need, some practices should be applied. The Institute of Electrical and Electronic Engineers (IEEE) published a standardization called Rapid PHY Selection (RPS), which offers to decrease the energy of an Ethernet network with very low utilization level. Furthermore, another possible solution is to use low energy consuming network products. For instance, 3Com company has produced switching products that provides a 78% power consumption savings over previously used products. The effects of using these new generation products are represented as below

"Given that a typical enterprise LAN has 100 Ethernet switches or about 2000 networked nodes, and taking into account that the switches are never turned off at night or put into sleep mode, the potential savings of moving to newer technology are enormous. By replacing some older generation Gigabit switches (e.g. 3Com 4924 with the newer 3Com 4200G) business would also gain a staggering extra 89.2W per switch. For 100 switches, this equates to:

- 77890 kWh saved which equates to 62 homes lit – An average home consumes 1,250kWh/year on lighting, based on the US Environmental Protection Agency (EPA) data.
- 78 % or USD5,530 saving per year on electricity costs - Based upon USD0.071cents per kWh electricity costs.

- 56 Tons of CO_2 reduced –1.43 lbs of CO_2 is emitted per kWh electricity generated according to US Energy Information Agency data.
- 10 cars removed from the roads - A car emits 11,560 lbs of CO_2 per year according to EPA data.
- 15 acres of trees planted – this represents acres of forest that would have to be planted to sequester the amount of carbon dioxide avoided due to energy savings from power management. Based upon a conversion of 7,333 lbs. CO_2 sequestered per acre of trees.[6]

2.6 Cooling Units

These devices are used in order to keep the data center and its equipments in appropriate temperature and humidity. Since all elements of data center produce heat while operating, there is a need to remove this heat otherwise it will decrease the reliability of the devices. Likewise, the humidity level should also be kept in a proper range. The traditional cooling systems in the data centers are Computer Room Air Conditioners (CRAC), Computer Room Air Handler (CRAH), Humidifier and chillers.

Traditional cooling systems

Computer Room Air Conditioners (CRAC)

- Refrigerant-based (DX), installed within the data center floor and connected to outside condensing units.
- Moves air throughout the data center via fan system, delivers cool air to the servers, returns exhaust air from the room

Computer Room Air Handler (CRAH)

- Chilled water based, installed on data center floor and connected to outside chiller plant.
- Moves air throughout the data center via fan system, delivers cool air to the servers, returns exhaust air from the room.

Humidifier

- Usually installed within CRAC / CRAH and replace water loss before the air exits the A/C units. Also available in standalone units.
- Ensures that humidity levels fall within ASHRAE's recommended range

Chiller

- Produces chilled water via refrigeration process.
- Delivers chilled water via pumps to CRAH.

Recent technologies

Free-Cooling

Free-cooling means to use the ambient air for cooling the chilled water or the inside air that removes the heat from the data centers. When the ambient temperature is under a specific value, the water or the air heated in the data center is allowed to move through the free-cooling system by a valve. The hot cooling element (either water or air) is cooled by using no power and then sent back to the data center cooling system. Since this system will decrease the need to use the air conditioning units, it will provide low power consumption, and also a high life-time of the air conditioning unit which will help to save money and also will bring benefits to environment in terms of e-waste.

Hot aisle / cold aisle Server Rack Configuration

It provides air separation within the server room. In this design, data center cabinets are aligned into alternating rows, which improves airflow management.

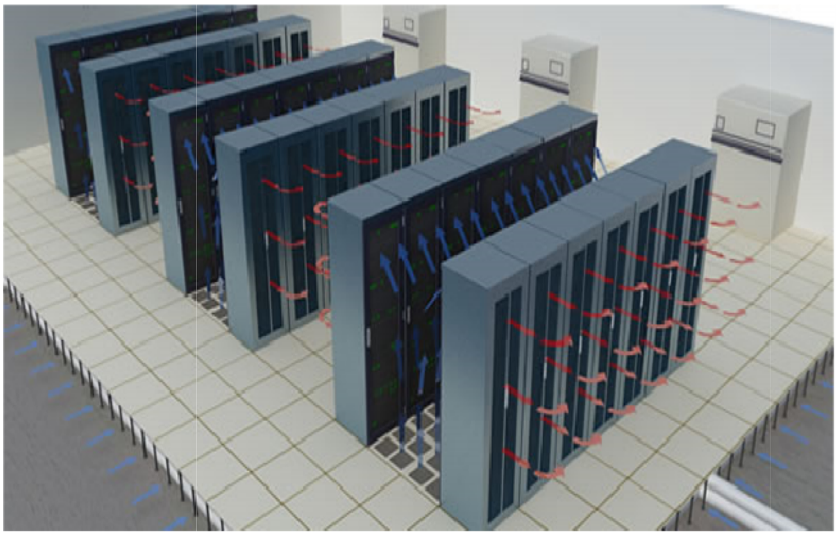

Figure 11 Hot aisle / cold aisle Server Rack Configuration

Efficient Air-Cooling System Design

Lawrence Berkeley National Laboratory report on efficient data center energy use displays some possible problems in air management to be addressed. According to this report, air-cooling can be improved by addressing the following list of problems

- short-circuited heated air on the top of around server rack
- the short-circuiting of cooled air back to air conditioner through the openings in raised floors such as cable openings and misplaced floor tiles with openings;
- misplaced raised-floor air-discharge tiles;
- poorly located computer room air conditioning units;
- inadequate ceiling height or an undersized hot-air return plenum;
- air blockage which are common with piping and large amount of cabling under raised floors
- openings in racks that allow air by-pass from hot areas to cold areas or vice versa
- poor air-flow through IT equipment racks caused by restrictions in rack structure

- IT equipment with side or top air discharge adjacent to front-to-rear discharge configurations
- Inappropriate under floor pressurization.

In fact, all these possible problems address to a few situations, mixing of hot air and cold air or air blockage. When these problems occur, a need to cool the air which was previously cooled will occur. Thus, providing an air-cooling that can separate the cold air from hot air and preventing these blockages would increase the cooling-unit efficiency and provide lower power consumption over cooling. Figure15 shows an appropriate air-cooling design.

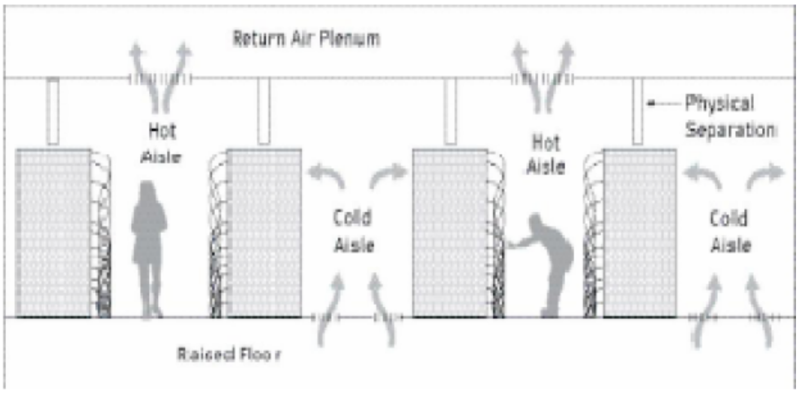

Figure12 Optimum Air-Flow Design to Separate the Hot Air from Cold Air

In addition to separate hot air aisles from cold air aisles, the openings that cause air leakage should be closed. Finally, the obstructions against the air flow should be overcome by better equipment placing and cabling. [7]

Centralized Cooling System

Another strategy to Green the cooling units is to use centralized air-cooling. In this cooling system, instead of using air conditioning for each computer rooms, all the heated air is collected and cooled by one center air conditioning unit. The benefits of this system are, since it uses very large sized fans it will bring electricity efficiency, the manageability of the cooling system is easier, the maintenance requirements is less than distributed cooling system and finally as centralized cooling uses water cooling instead of water-and-air cooling it will provide better efficiency.

3 Green Performance Indicators for Data Center Assessment

3.1 Established Institutions of Reference

There are two main pioneers in the field of data center evaluation. They are the Green grid and Uptime Institute. They can be seen as the junction between other important institutions and big companies that are interested in new technologies within that field. Just to list a few of them, they are The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), The Distributed Management Task Force (DMTF), and The Storage Networking Industry Association (SNIA).

With governmental support we have institutions like the US Department of Energy (DOE), US Environmental Protection Agency (EPA), Green IT Promotion Council (GIPC) and Information Technology Industry Council (ITI)

The Green Grid

Founded on 26th February of 2007, it has evolved today as a global consortium that works worldwide closely together with end-users, technology providers and governments. They are dedicated to the creation of standards and metrics to help owners of data centers to run them more efficiently. They are specialized in 3 main fields:

- To define meaningful, user- centric models and metrics;
- To promote the adoption of energy efficient standards, processes, measurement methods and technologies;
- To develop standards, measurement methods, processes and new technologies to improve performance against the defined metrics

Examples of famous members of the Green Grid are companies such as Microsoft, IBM, Oracle, HP, Intel or AMD. The webpage offers a wide range of information. In the section library & tools are free downloads provided to the public. One can find white papers about the newest trends in this field or even small applications for evaluating efficiencies in the Data Center.[8]

Uptime Institute

Founded in 1993, today Uptime Institute is providing education, publications, consulting, certifications, conferences and seminars, independent research, and thought leadership for the data center industry. Clients are mostly big companies, owning data centers in dimensions of 50000 square feet and consuming together around six megawatts of utility power. There is a lot of effort put into the research on data center facilities. The goal is to find Best Practices and make them available to the members of the Institute. Some of the innovations developed by Uptime are hot/cold aisles, site infrastructure energy overhead metrics and measurements, cost modeling, the dual-power specification and tolerance of data center facilities. Furthermore Uptime Institute offers:[9]

- Annual international Symposium on Green Enterprise IT
- Collaboration with other establishments (i.e. also with the Green Grid)
- Elaboration of an data center-specific LEED program
- Software tools

3.2 Definition of Green performance Indicators

Green Performance Indicators (GPIs) are metrics that are able to evaluate the efficiency features of the Datacenter and support its sustainable operation. A metric is considered as a GPI depending upon its capability to measure the efficiency features either at the datacenter level or at the individual component level of the datacenter.

3.3 Importance of Green performance Indicators

GPI's help in measuring the environmental impact caused by the Datacenter i.e. the carbon footprint emission level. These indicators provide the CIO's with the actual performance level of the company's Datacenter. They help the company to identify the areas of improvement, and also assist them in planning their strategy of "Going Green". The metrics used for Data Center efficiency assessment consider mostly energy consumption and usage. They provide an "as is" assessment, which gives a picture of the actual state of the Data Center, with the goal to detect eventually inefficiency losses within the system. To calculate these metrics, it is crucial to gather rudimentary data of the system first, as being the starting point of a holistic efficiency analysis. These data are used to calculate a wide range of specific metrics of significance.

3.4 Summary of the Green Performance Indicators and Clusterization

Metrics are the backbone of the Data Center efficiency assessment. A big diversity of metrics is presented here for quantifying and comparing efficiencies relevant to Data Centers. The collection of the successive metrics is the state of the art and refers to commonly used metrics in the industry. They were found while screening various reliable sources, such as the institutions mentioned above "The Green Grid" and "Uptime Institute", and references within the technical literature. These metrics are the GPI's for Data Center assessment.

The metrics are clustered into three categories, namely Energy Impact Assessment, IT infrastructure assessment and Facilities Assessment.

Metric	Energy Impact	IT Infrastructure	Facilities
PUE (Power UsageEffectiveness)	X		
DCiE (DatacenterInfrastructureEfficiency)	X		
DCeP (Data Center Energy Productivity)	X		
SI-EER (Site Infrastructure Energy Efficiency Ratio)	X		
SI-POM (Site Infrastructure Power Overhead Multiplier)	X		
H-POM (IT Hardware Overhead Multiplier)	X		
DH-UR (Deployed Hardware Utilization Ratio)		X	
DH-UE (Deployed Hardware UtilizationEfficiency)		X	
Ratio of IT Equipment to HVAC Load			X
Ratio of HVAC Power to Computer Power			X
Computer LoadDensity		X	
U_{server}[Server Utilization]		X	
$U_{storage}$[StorageUtilization]		X	
$U_{network}$[NetworkUtilization]		X	
Total Power Consumption	X		
EnergyBench		X	
SWaP		X	
CarbonfootprintEnvironmental Impact	X		
Telecommunications Energy Efficiency Ratio (TEER)		X	
CADE [Corporate Average Data Efficiency]	X		
DCPE(Data center Performance Efficiency)	X		
IOPS / Watt		X	
Technology Carbonefficiency(TCE)		X	
Data Center Energy Efficiency and Productivity Index (DC-EEP Index)	X		X
RackCooling Index (RCI)			X
Return Temperature Index (RTI)			X

Total	**11**	**11**	**5**

Table 3 Macro level clusterization of metrics

This type of clusterization facilitates the evaluation and allows customizing the improvement strategies pertinent to the category of the assessment under consideration. From the table it becomes clear that there are eleven metrics each in the Energy Impact Assessment and in IT infrastructure Assessment, and five metrics in the Facilities assessment. Also when comparing number of metrics to measure the IT infrastructure to the number of metrics to measure facilities, it is recognizable that there are more metrics to assess the IT infrastructure. One reason is that, referring to the theory of "Energy Proportionality Design", the right approach to improve efficiency is to start at the processing components. Another reason is simply the elevated complexity of the components.

It is also important to define each category of clusterization, which justifies the need for such type of clusterization.

Energy Impact Assessment

The metrics grouped in this category assess the overall energy efficiency of the datacenter including its components and facilities.

IT infrastructure Assessment

The metrics grouped in this category, assess the IT infrastructure of the Datacenter. The IT infrastructure includes all components that are involved in computing, such as Servers, Storage devices, networking equipments, monitoring or controlling workstations machines, CPUs, IT hardware power supply and IT hardware fan.

Facilities Assessment

The metrics grouped in this category, assess the performance of the facility. It includes all components that support computing; such as power delivery systems, cooling systems and lighting.

Clusterization according the functional parts of a Data Center

Since the clusterization above is a macro- approach, yet another diversification is being made at the micro level. At the micro level the metrics are classified under the functional parts of the Datacenter. The Classification is clustered into overall Data Center Assessment (often referred to as KPIs), Cooling Units, Network, and Server and Storage Assessment, represent the different functional parts of a data center. Thus the table given below provides an overview of the metrics that are available to monitor the different functional components.

Data Center Assessment	Cooling Unit Assessment	NetworkAssessment	Server Assessment	StorageAssessment
PUE	IT Equipment Load / HVAC Load	$U_{network}$ [NetworkUtilization]	U_{server} [Server Utilization]	$U_{storage}$ [StorageUtilization]
DCiE	HVAC Power / Computer Power	Telecommunication Energy Efficiency Ratio (TEER)	SWaP	IOPS per Watt
DCeP	RackCooling Index		EnergyBench	
SI-EER				
SI-POM				
H-POM				
DH-UR				
DH-UE				
Total Power Consumption				
Carbon Footprint Environmental Impact				
TCE				
C.A.D.E.				
DC-EEP				
Computer LoadDensity.				

Table 4 Micro level clusterization

3.5 Description of the Metrics

3.5.1 Existing Metrics Used for Data Center Assessment

PUE: Power Usage Effectiveness &DCiE: Datacenter Infrastructure Efficiency

The PUE (Power Usage Effectiveness) is a metric that is used for determining the data center energy efficiency. It is calculated by dividing the total data center power consumption to the power consumed by the IT infrastructure. DCiE (Data Center infrastructure Efficiency) metric is also used for measuring the data center power efficiency, by taking the ratio of the energy consumed by the IT equipment of the data center, to the overall power consumption of the data center. It is actually an inverse of PUE.

PUE = Total Facility Power/IT Equipment Power

DCiE = 1/PUE = (IT Equipment Power/Total Facility Power) x 100%

Thus PUE and DCiE provide efficiency measures, which are used for comparing the energy efficient performance of one datacenter with the other.

IT equipment power refers to the power associated with all IT equipments such as compute, storage, and network equipment, along with supplemental equipment such as KVM switches, monitors, and workstations/laptops which are used to monitor or control the datacenter

Total Facility Power includes power consumption of all equipments that supports the IT equipment load

• Power delivery components such as UPS, switch gear, generators, PDUs, batteries, and distribution losses external to the IT equipment.

• Cooling system components such as chillers, computer room air conditioning units (CRACs), and direct expansion air handler (DX) units, pumps, and cooling towers.

• Compute, network, and storage nodes.

• Other miscellaneous component loads such as datacenter lighting.[10]

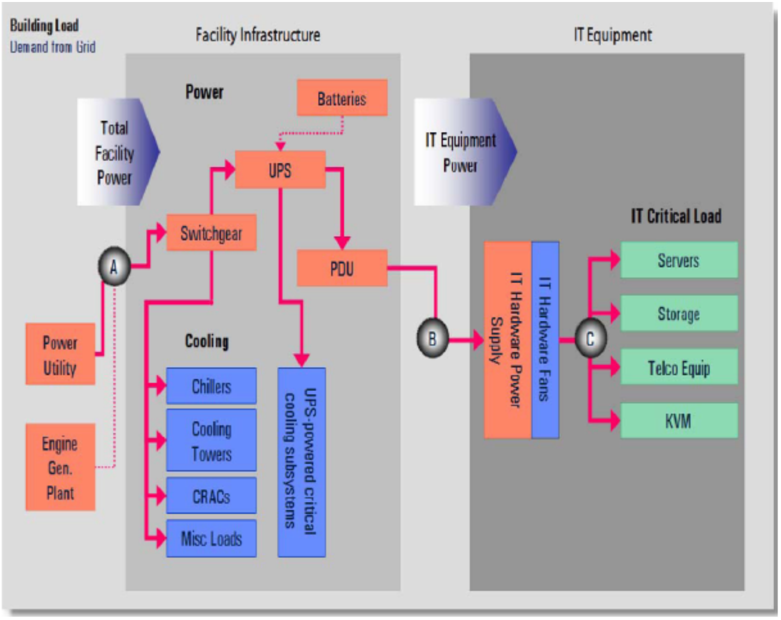

Figure 13 Elements of PUE and DCiE

DCeP: Data Center energy Productivity

DCeP measures the amount of energy consumed for producing useful work. It can be calculated for a single device or a group of IT equipments. This metric provides an "assessment window" where useful work and energy are compared over a user defined time period.

DCeP = Useful Work Produced / Total Data Center Energy Consumed over time

Useful work produced is calculated by the measuring tasks performed by the hardware during the assessment window. The assessment window is the specific time window that is established in order to quantify the energy consumed while executing the measurement. Tasks should be as specific as possible, while the assessment window should be no shorter than about 20 times the mean run time of any of the tasks initiated in the assessment window. A datacenter should define both figures according to their workload and business model.

The Green Grid proposes the following equation for useful work: (Sum of all tasks * Value of the task) * Time Based Utility Function * Absolute Time of Completion

This equation recognizes that some tasks are more important than others. Some of them are mission critical (task value) while others may involve a response time that is an integral part of SLA (Time based utility function).[11]

SI-EER: Site Infrastructure Energy Efficiency Ratio

This metric is used for determining the efficiency of data center's site infrastructure system. The ratio of power consumed by all mechanical and electrical systems supporting the IT equipment load (total power load) divided by the IT equipment load (critical load) is the data center's site infrastructure energy efficiency measurement. Measures the kilowatts required from the outside (local) utility to deliver one kilowatt of reliable power to the IT equipment.[12]

SI-EER =Total Power Load / Critical Load

SI-POM: Site Infrastructure Power Overhead Multiplier

SI-POM is a dimensionless ratio that tells the data center operators how much of a data center's site power is consumed in over head, instead of making it to the critical IT equipment.It is the ratio of data center power consumption at the utility meter over the total hardware power consumption at the plug for all IT equipment. It gives the engineers and managers a good idea of the energy-efficiency maintained by the facilities components such as transformers, UPS systems, PDUs, cooling systems and lights.[12]

SI-POM =Data Center Power Cons. / Total Hardware Power Cons.

H-POM: IT Hardware Overhead Multiplier

H-POM is also a dimensionless ratio which tells the data center operators how much of the power input to a piece of hardware is wasted in power supply conversion losses or diverted to internal fans, rather than making it use to the components within the device. It is the ratio of AC hardware load at the plug to the DC hardware compute load, (i.e. The amount of power consumed by the computing components within the IT equipment). For an entire data center, this metric is the ratio of the total hardware load at the plug across all datacenter equipment over the hardware compute load for all IT equipments in the datacenter. The goal is to lower the overall ratio to provide the datacenter with more compute performance using less power.

H-POM =AC Hardware Load / DC Hardware Compute Load

DH-UR: Deployed Hardware Utilization Ratio

DH-UR metric helps in quantifying the fraction of power wasted or drained by idle systems. Datacenters with a DH-UR rating as close to 1 as possible without disrupting availability are considered as efficient datacenters. [12]

DH-UR ratio for servers =Number of Servers Running Live Applications / Total Number of Servers Deployed

DH-UR ratio for Storage = Number of Terabytes of storage containing frequently accessed data (Within the last 90 days)/ Total terabytes of storage deployed

DH-UE: Deployed Hardware Utilization Efficiency

DH-UE measures power efficiency of operating servers and storage systems. DH-UE for servers is the ratio of minimum number of systems necessary to handle peak compute load divided by the total number of systems deployed. This metric provides the opportunity for servers and storage devices to increase their utilization by virtualization. [12]

DH-UR ratio for servers =Min. no of Systems Necessary to Handle Peak Compute Load / Total no of Systems Deployed

Total Power Consumption

It is the cost of power consumed in Kilowatts. It gives a rough quantitative idea of the amount of energy necessary to operate the DC. From there first estimations can be made whether concerning the size of the data center it is using too much energy. It is not a metric in the actual sense, since it is only a single value and no direct connection to other indicators. It can be used to illustrate after having optimized the data center the degree of improvement / savings obtained. However it also measures the organizational efficiency in energy savings.

Carbon footprint Environmental Impact

It is described as "the total set of Greenhouse gases emissions caused by an organization, event or product". It can be expressed in the amount of carbon dioxide emitted. For a data center owner it should be self-evident to measure the carbon footprint. Anyway it is expected to be obligatory sooner or later due to political arrangements. Apart from that, again it is also a good metric to show up efficiency problems. A low carbon footprint is not necessarily an indicator for efficiency, but it can give a good estimation about it when compared to the size of the data center.

To be used in this context, it is crucial to know how to calculate the carbon footprint. It can be divided into 2 main areas; the products installed and the electricity used. For the latter there is abundant data available, either provided by the energy company where the electricity is getting purchased, or if produced on site, there are tables that give the emitted CO_2 according to the quantity and type of raw material used. The products installed on the other hand, are way more difficult to evaluate. There do tables exist, but it is evident an exact estimation will not be possible.

That means, the carbon footprint impact is not a metric that can be monitored in the data center but it is a Green performance indicator that gives a rough estimation on the data centers environmental impact.[13]

C.A.D.E. – Corporate Average Data Efficiency

Developed by McKinsey&Co, it is used to measure the overall energy efficiency of data centers. It is the combination which aid in measuring the energy efficiency and utilization of IT equipment / facilities into one single indicator (in percent). Whereas the higher the CADE, the more efficiently does the data centre work. The problem is that, for example if a downed server is getting removed, that would mean an increase in utilization. CADE wouldn't reflect that gain accurate enough. CADE can be a powerful metric if used on a common base [14]

CADE = Facility Efficiency (FA) x IT Asset Efficiency (AE).

FE = (Facility Energy Efficiency) x (Facility Utilization)

AE = (IT Energy Efficiency) x (IT utilization)

Data Center Energy Efficiency and Productivity Index (DC-EEP Index)

It is a fusion of two independent but unrelated ratios (IT-PEW and SI-EER), one dedicated to the IT and the other dedicated to the facility. Hence, IT-PEW must be estimated by the data center owner. It depends on the data architecture and reliability decisions. It is defined upon the amount of equipment necessary to obtain desired time and availability SL, amount of stored copies, disaster recovery strategies etc. The IT-PEW, if not calculated by the data center owner himself, can be found out by checking the "Server Measurement Protocol" provided by the Uptime institute. It enables benchmark comparisons according to various product lines. The DC-EEP therefore accounts for the output of IT productivity in terms of information output, and the intake of energy per watt of the facility infrastructure. In short words, the DC-EEP identifies how a technical and operational choice for cooling equipment significantly affects energy consumption via the SEER ratio and hence it is an optimal GPI.

DC-EEP=IT Productivity per Embedded Watt (IT-PEW) X Site Infrastructure Energy Efficiency Ratio (SI-EER)[15]

Technology Carbon efficiency (TCE)

As to weed out the shortcomings of the "Carbon footprint Environmental Impact" metric, the TCE measures the real environmental impact and IT carbon performance and data center efficiency analysis.[16]

TCE =PUE X Electricity Carbon emission rate

Computer Load Density

The last metric in the overall data center assessment is the computer load density. The computer load density means the power needed in computational processes per each square meter area of computing element. There is a variation in the electric power density in the data centers. Figure14 shows the various computer load density values for different data centers. This metrics define how effectively the power is used in computational process[17]

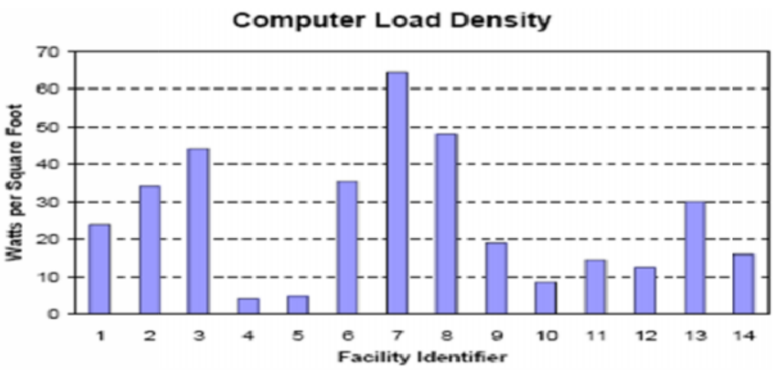

Figure14 Computer Load Density

3.5.2 Metrics Used for Cooling Unit Assessment

Ratio of IT Equipment to HVAC Load

One of the ratios that is used in order to evaluate the performance of cooling units in data centers, is the ratio of power used for overall IT equipment to power used for heating, ventilating and air conditioning. This ratio indicates the efficiency of the cooling units. Figure15 shows the IT Equipment load / HVAC Load values for different datacenters.

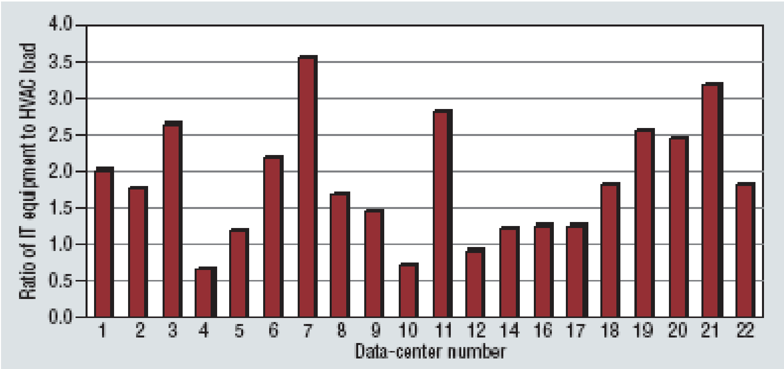

Figure15 IT Equipment load / HVAC Load

The higher value of the IT Equipment load / HVAC Load means the higher efficiency of the cooling unit of the datacenter. According to Figure15, different datacenters have better efficiency than the others, which means the cooling units of these datacenters can remove the heat with less power and therefore more power is provided to computational processes.

HVAC Power / Computer Power

Similar to the IT Equipment load / HVAC Load, another criterion that measures the efficiency of the cooling unit is the ratio of the power used in cooling system to the power used in computational processes. Figure16 gives different values of this ratio according to different data centers.

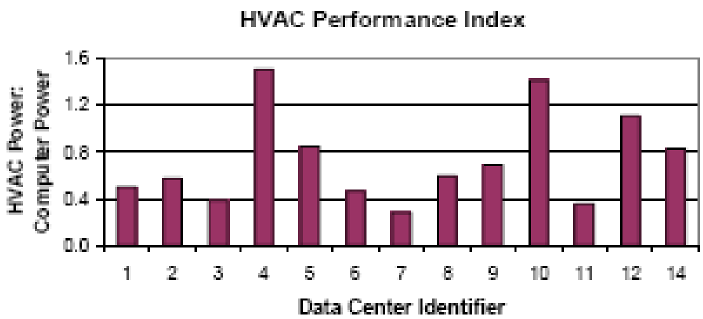

Figure16 HVAC Power / Computer Power

Unlike the ratio of IT Equipment load / HVAC Load, the lower the HVAC Power / Computer Power, the more efficient the cooling system. The variations of the data on both of these metrics on Figure-15 and Figure-16 gives an idea that there is still opportunities to increase the efficiency of the cooling unit for many of the data centers and get energy savings and reach an eco-friendly datacenter HVAC.

Rack Cooling Index

Is used to gauge how effectively the equipment racks are cooled and maintained within thermal guidelines or standards. This metric shows in a simple way how effective the cooling system is performing. Scope is to reduce or eliminate over temperatures, being the cause of harming electronic equipment or interrupting critical services. As the following table shows, the RCI values range usually between 90% and 100%, whereas the latter is the best.[18]

(RCI. sub. HI) = (1 – (total Over-Temp. / Max Allowable Over-Temp.)) x 100%

Rating	RCI
Ideal	100%
Good	≥96%
Acceptable	91%–95%
Poor	≤90%

Figure17 Suggested RCI quality ratings using ASHARE Class I environment

Hence, the RCI is a useful indicator to improve the system in terms of:

- Designing the environment of equipment; by combining RCI with CFD modeling. (see picture below)
- Providing specifics on design: users can buy a predefined level of RCI they need.
- Monitoring the environment of equipment: real-time monitoring is feasible.
- Helping research and development: strive for inventing products that reach RCI = 100%

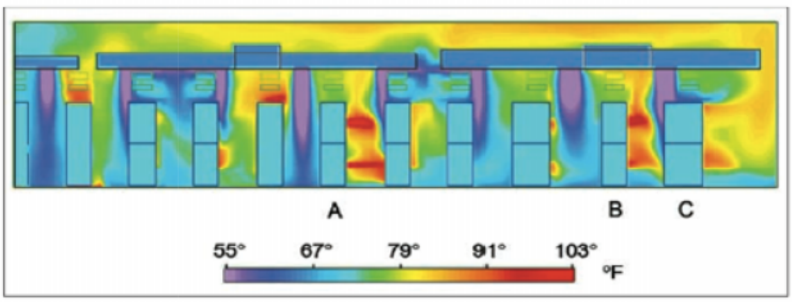

Figure18 Point loads on perimeter aisle, line up C (section view)

Return Temperature Index (RTI)

Allows the HVAC equipment to operate more efficiently. It is also a measure of the excess or deficit of supply air to the server equipment. The Return Temperature Index measures the energy performance of the air-handling equipment. It should be close to 100% to have the best performance; a deviation means losses in performance; a rise indicates overutilization, provoked by air recirculation elevating the return air temperature; a decline could imply a by-pass. These interconnections are shown in the following figure[19]

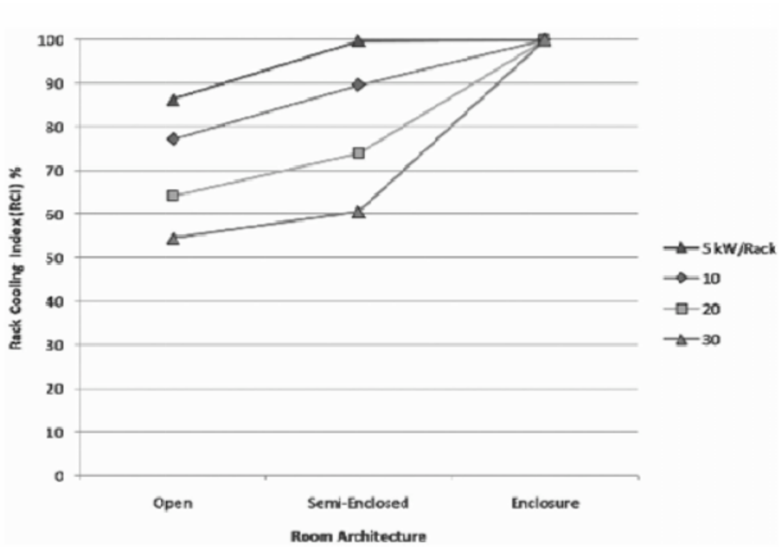

Figure19 RCI_{HI} as a function of heat density and room architecture

Furthermore the figure explains the dependencies of increasing the air-flow volume and/or reducing the air inflow temperature. Usually it is difficult (especially for racks with higher power) to achieve a RCI of 100% only by increasing the air-flow volume.

The temperature rise across the electronic equipment carries the maximum temperature potential of the return air. Hence, the return air is only subject of relevance, if brought in connection with the Equip, which the RTI does. Hence, the RTI in combination with the RCI give a perfect picture over the HVAC efficiency.

RTI = [(TReturn – TSupply) / ΔTEquip] x 100% ,Where:

TReturn = return air temperature (weighted average)

TSupply = supply air temperature (weighted average)

ΔTEquip = temperature rise across the electronic equipment (weighted average)

3.5.3 Metrics Used for Server Assessment

U server [Server Utilization]

This indicator is created by Green grid are used for quick assessment and comparing the operational efficiency and productivity potential of the datacenter in more than one dimension. It measures the activity of the processor relative to its maximum ability in the highest frequency state.[20]

EnergyBench

It is given as the throughput per Joule. It measures the performance of the processor in terms of how much is the actual energy consumption. This can be crucial to know, since the actual OEM specifications differ very often from the actual consumption. The discrepancies between the real and suggested consumption is a common problem, which concerns most of the components.

SWaP

It is calculated by SWaP = Performance / (Space x Watts). It is used to estimate the server efficiency; the higher the value, the more efficient is the server. To validate the usefulness of this metric, the following table shows a simple example of how efficiencies can vary while producing the same output. The server A and server B do have the same performance (500 operations), but differ in space (A half of B) and power (A 2,7x of B). Using the formula we find server A having a value of 0,83, while server B a value of 0,16. This makes server A 5,2 times more efficient than server B.

	Server A	Server B	Improvement
Operations	500	500	same
Space	2RU	4RU	2x
Power	300	800	2,7x
SWaP	0,83	0,16	5,2x

Table 5 SWaP for different Server

3.5.4 Metrics Used for Storage Assessment

$U_{storage}$ [Storage Utilization]

This indicator is created by Green grid are used for quick assessment and comparing the operational efficiency and productivity potential of the datacenter in more than one dimension. It measures the percentage of storage used relative to the overall storage capacity within the data center

IOPS / Watt

This Indicator shows how effectively energy is being used to perform a given amount of work. Other examples would be bandwidth per watt, transactions per watt or users / streams per watt. As for using an activity based approach, a combination with another metric that includes the supporting capacity per watt. IOPS is a common benchmark for storage devices and can be measured with applications such as Iometer by Intel. So this is a good benchmark to assess the efficiency of the storage devices. [21]

Number of I/O operations (per second) / energy used by the storage system (watts)

3.5.5 Metrics Used for Network Assessment

$U_{network}$ [Network Utilization]

This indicator is created by Green grid are used for quick assessment and comparing the operational efficiency and productivity potential of the datacenter in more than one dimension. It measures the percentage of bandwidth used relative to the bandwidth capacity in the data center

Telecommunication Energy Efficiency Ratio (TEER)

It is the network component's ratio of "work performed" to "energy consumed" and used to measure and report the energy consumption. The ATIS (Alliance for Telecommunications industry Solutions) has released a standard methodology for TEER. Scope is to uniformly quantify the before mentioned ratio. Usually the efficiency standards are determined by 4 instances, the type, the location of the network as well as the classification. Due to the uniformity, it is now possible to have a real possibility to compare the equipments. It is a systemized and repeatable assessment of the energy consumption. This implies that, due to the vague definition of "work performed", that without having an appropriate framework of relevance, the TEER is only useful for the very own application and interpretation respectively. Without a measure of reference it will be impossible to estimate the actual efficiency of the own system. On the other hand, one could very well make up his own thoughts for how to use this metric. In that case it is a highly customized, individual indicator for insiders. [22]

3.6 Evaluation of the Green performance Indicators

The metrics are being analyzed according to the two main criteria qualitative evaluation and relevance of use as GPI within Data Centers.

Qualitative evaluation in the sense of:

- Ease of calculation - is professional knowledge needed to obtain results.
- Ease of interpretation - is a profound background knowledge needed to understand the metric.
- Completeness - are all variables included or are some missed out.
- Objectiveness
- Accuracy

For the relevance of use as GPI within data Centers, it is crucial to evaluate the meaning of each metric and its significance thoroughly.

3.6.1 Metrics used for Data Center Assessment

PUE and DCiE

PUE and DCiE are two metrics, which are very useful to use, since they give an idea about how effective the power is used. The effective use of the power means that most of the power consumed within the Data Center is consumed directly in computational processes instead of supporting operations. Thus, these two metrics are very crucial in the datacenter evaluations.

It is possible to demonstrate the energy allocation in the Data Center differently by using this two metrics. For instance, if a PUE is settled up to be 3.0, it shows that the Data Center demand has much more energy to power IT equipment. This energy is three times more than necessary. Besides, also the real impact of the system's power demand can be calculated by using the ratio. For example, if the Data Center's PUE is 3.0 and the demand of the server is 1000 Watts, then the necessity of the power is 1000 Watts for utility grid and 3000 Watts for the server. Also the DCiE value could be used in a simple manner. When the DCiE value is 33%, it means 33% of the Data Center's power is consumed by the IT equipment.

Data Centers usually don't represent as the only part of the building; typically there are also other facilities connected. For this reason, the datacenter administrator should be aware of this situation and measure the amount of power, which is consumed by the other parts for avoiding errors of electricity consumption calculations.

PUE	DCiE	Level of Efficiency
3.0	33%	VeryInefficient
2.5	40%	Inefficient
2.0	50%	Average
1.5	67%	Efficient
1.2	83%	VeryEfficient

Table6PUE/ DCiE Level Efficiency

Following research of the Green Grid, the PUE can have a minimum value of 1.0 and the maximum is theoretically infinite. The value 1.0 represents the optimum, having an efficiency of 100%. That means that all the power is used by IT equipment only. Due to the rare monitoring actions undertaken by network administrators, there are only a few data sets available to illustrate the total spread of efficiencies. The data evaluated up to this point shows nevertheless, that most data centers have a PUE of 3.0 or more. Having the right setup, it is possible to obtain easily a PUE of 1.6. This theory is being underlined by the Lawrence Berkley National Labs. It shows that after measuring 22 data centers, the values for the PUE ranged between 1.3 and 3.0. Furthermore it was indicated that indeed a good setup can lead to values of 2.0. But as mentioned before the available data for this industry doesn't allow a proper evaluation[37].

DCeP

DCeP is a precise metric and it is the first one ever developed that takes useful work into account. However, this metric has some weaknesses. In order to reach the final value of the metric, the user has to determine the assessment window, set values to specific tasks and calculate the useful work. Here the most obvious weakness is that it can be difficult, costly and time-consuming to measure these values. So applying this metric could create inefficiencies itself. Since the main objective is to find out the inefficiency and make improvements, this kind of a metric would not be of much use. This means, that the metric is a rather objective metric. The values that need to be assigned depend deeply on the interpretation of the user (i.e. value of the task). On the other hand, once defined in a proper way, it can be a powerful metric to the individual. Especially applied in fields with simple structured and frequently recurring tasks.

SI-EER

SI-EER metric is an identical metric to PUE and hence it is as complete and useful as PUE. In other words, it does use the same input data (IT Equipment Power and Total Facility Power). The companies should select and use just one of them as a Green Performance Indicator instead of both for evaluating their data center efficiency.SI-EER was created by The Uptime Institute, whereas PUE is created by Green Grid. Green Grid is a more popular and widely known organization and moreover PUE was created before SI-EER. For these reasons PUE is more commonly used.

SI-POM same as PUE

Similar to the SI-EER and PUE relationship, SI-POM is an alternative of the DCiE metric. It is also as useful as DCiE. The companies should select and use just one of them as a Green Performance Indicator instead of both for evaluating their data center efficiency.

H-POM

H-POM is a dimensionless metric that displays how much of the power is lost during the power conversion. It is using the AC load value and the DC value. At this point it is very important to be aware of what data is accessible or needed respectively. The ratio makes only sense when applied properly. For example to estimate the power used only for computational processes, there is a detailed component monitoring necessary and/or reliable OEM specifications, broken down to the very relevant computing devices. In other words, the metric can be used on different levels, the single device level or data center level. Anyhow, the H-POM metric can be very useful to uncover inefficiencies.

DH-UR

Deployed Hardware Utilization Ratio considers the utilization level of all the hardware used within the data center. So, by this metric it is possible to see the evaluation of the whole datacenter hardware. But, this information provided by DH-UR will not give a solid solution since it will not be possible to understand which sub part of the data center works with low utilization. Again it is crucial to interpret it in the proper way. For example, as mentioned earlier in this paper, it is possible to obtain the utilization ratio of the servers by estimating the number of servers that run live applications, compared to the total number of servers deployed. And this is indeed a very useful indicator, since it enables someone to estimate inefficiencies due to an oversized server pool.

DH-UE

In addition to DH-UR, there is the Deployed Hardware Utilization Efficiency metric. This metric is complementary in the sense that it pictures the inefficiency on a higher hierarchy level. It compares the utilization efficiencies of the servers, storage units and the networking units – the system – with the total number of systems deployed. It remains in the eye of the user to decide how far in detail he wants to monitor the efficiency. In most of the cases it might be enough to look solely at the system, especially if the system is considered as a single, not to be modified unit.

3.6.2 Metrics Used for Cooling Units Assessment

With one of the highest energy consumption rate in the datacenters, the Greenness of the HVAC unit in a data center should be examined. The criteria for this evaluation are IT Equipment Load / HVAC Load and HVAC Power / Computer Power.Among the cooling unit evaluation metrics, the ratio of IT Equipment to HVAC Load and HVAC Power / Computer Power metrics are used to see the power consumption rate of the HVAC in data center. Therefore they are very beneficial to see the opportunities to save energy from the Greening strategies of the cooling units, because it shows quite clearly how much energy is being used by the HVAC in comparison to the other installations. Generally speaking, a low HVAC load and HVAC power value respectively are desirable.

Return Temperature Index (RTI)

RTI measures the level of bypass air or recirculation air in the equipment. This metric is important because recirculation air is the main reason for hotspots in the datacenter. It provides information for improving the conventional open room architecture by increasing the airflow.

Rack cooling Index

It measures how well the equipment cools the electronics with the manufacturer's specification. RCI when combined with cost function can be used for evaluating the current or planned equipment room designs. It also helps in choosing the correct thermal architecture for the data center. Some of the usefulness of RCI are Design Equipment Environments, Provide Design Specifications of thermal quality for Data center owners/operators ,Assess Equipment Environments and Help Product Development/Marketing with the concept of cooling.

3.6.3 Metrics Used for Server Assessment

U server [Server Utilization] Energy Bench and SWaP are the three metrics that we consider for the server assessment. We measure the utility, performance and efficiency aspect of the server using these metrics.

3.6.4 Metrics Used for Storage Assessment

U storage [Storage Utilization] and IOPS / Watt are the metrics that are widely used for storage assessment. These two metrics assess the utility aspect and its energy efficiency aspect of the storage devices

3.6.5 Metrics Used for Network Assessment

U network [Network Utilization] and Telecommunication Energy Efficiency Ratio (TEER) are the two metrics that we consider for the network assessment. These two metrics also assess the utility aspect and its energy efficiency aspect of the network devices.

3.7 Final Evaluation of the Metrics

3.7.1 Preliminary Considerations

To elaborate the dependencies between the metrics it is crucial to start with the variables. Most of the metrics can be broken down to a set of single rudimentary variables. Some though, are already very basic and/or there is no value or need for a more detailed pruning i.e. “Total Facility Power”. These variables then sometimes do have a different verbal definition, while having the same meaning. This is due to the fact, that the data center assessment metrics belong to a emerging market that is not matured and standardized enough as yet. There are a vast number of sources of different institutions and companies that express the same variables differently. Hence a qualitative analysis is necessary to clear out contradictions.

The advantage is that after clearing the redundancies, the dependencies between the variables and also between the metrics become clear without any contradictions. Furthermore it enables one to estimate the importance of monitoring specific parts of the data center, or in other words, which parts are absolutely crucial to be monitored to obtain an adequate efficiency assessment of the data center.

3.7.2 Estimating Dependencies

3.7.2.1 Presentation of the Variables and Description

The variables are the single segments of which the metric-formula is composed. They represent the smallest units monitored within a Data Center. In the table below all of them are listed as they occur, including also a short description of what they stand for.

Variable	Description	Unit
Total facility power	Total data center power consumption	(WATT)
IT Equipment Power	Power consumed by IT infrastructure	(WATT)
Useful Work Produced	(Sum of all tasks * Value of the task) * Time Based Utility Function * Absolute Time of Completion	(Time)
Total Data Center Energy consumed over time	Like total facility power, only that it is concerned for a specific period of time.	(WATT)
Total Power Load	All power consumed by all mechanical and electrical systems supporting the IT equipment load	(WATT)
Critical load	Site infrastructure energy efficiency measurement. Output of the PDUs or RPPs	(WATT)
Data Center Power Consumption	DC power consumption at utility meter	(WATT)
Total HW Power Consumption	Power consumption at plug for all IT equipment	(WATT)
AC HW load	AC HW load at the plug	(WATT)
DC HW compute load	Amount of power used only by computing	(WATT)

	components	
Number of Servers Running live applications	-	(#)
Total Number of Servers Deployed	-	(#)
Number of Terra-bytes of storage containing frequently accessed data	-	(Terra-bytes)
Total Terra-bytes of storage deployed	-	(Terra-bytes)
Min. Number of Systems necessary to handle peak compute load	System Storage and Servers	(#)
Total number of systems deployed	System Storage and Servers	(#)
IT Equipment Load	Overall IT equipment	(WATT)
HVAC load	Power for heating, ventilation and air conditioning	(WATT)
HVAC Power	Same as HVAC load	(WATT)
Computer Power	Power used for computational processes	(WATT)
Computer load density	Power needed in computational processes per each square meter area of computing element	(WATT)
Designed load density	Expected power needed	(WATT)
Facility Efficiency	Is the measure of Facility Energy Efficiency and Facility Utilization	(%)
Facility Energy Efficiency	Measure of Actual IT load to the Total power consumed by the data center	(%)
Actual IT load	Overall IT equipment	(WATT)
Total power consumption	Total data center power consumption	(WATT)
Facility Utilization	Measure of Actual IT load to the Facility capacity	(%)
Actual IT load	Overall IT equipment	(WATT)
Facility capacity	Overall IT equipment available	(WATT)
IT Asset Efficiency	Measure of IT Utilization and IT Energy Efficiency	(%)
IT Utilization	Average CPU utilization	(%)
IT Energy Efficiency	Measure CPU Loading to Total CPU power	(%)
CPU Loading	number of processes in the run queue	(#)
Total CPU	Total power at the CPU	(WATT)
Electricity Carbon emission rate	Carbon dioxide emissions at the facility	(g/10^6 J)
IT Productivity Per Embedded Watt	Useful work per usage of Watt	(#)
Over temperature	Temperature above the maximum recommended temperature at the equipment racks	Fahrenheit or degrees
Allowable over temperature	Recommended temperature temp at the equipment racks	Fahrenheit or degrees
([[DELTA][T.sub.AHI]	Difference between the Supply Air Temperature and Return Air Temperature	Fahrenheit or degrees
[DELTA][T.sub.Equip]]	Difference b/w the Rack inlet mean temperature and Rack outlet temperature	Fahrenheit or degrees

Table 7 Variables Description of the metrics

3.7.2.2 Identification of identical Variables

As mentioned in the preliminary considerations, it can be difficult to prove the actual dependencies for all metrics. The source of inaccuracy lies in the different ways of an individual interpretation of the variables. Some of them may be named differently, but actually monitoring the same. As a consequence an approach is needed that evaluates these variables absolute objectively. The only way of reaching that goal is to connect the variables to a physical space. Hence, they will be related to the components, which they are monitoring. This is especially valid for all the variables that measure energy performance. For the other variables that have a different attribute, such as “allowable over Temperature” or “IT Productivity per embedded Watt” this measure can be seen purely for the sake of confirming their independence. First, these variables don’t carry the danger of being misinterpreted, because they are very simple and commonly established. Second, they are single values and therefore show no dependency with other variables. Table 8 illustrates the relation between the single variables and the components they are taking into account:

S.No	Variables	**Power Delivery components** (UPS,Switch,Generators,PDU's, Batteries,Transformers)	**Cooling System Components** (Chillers,CRAC's,direct expansion air handler DX units,pumps,Cooling tower,heat exchangers)	**Nodes** (For stoarge,Network)	**IT Infrastructure**			**Other** (Data center lighting)
					Servers (CPU,Storage,RAM	Storagedevices, Networking equipments, monitoring/controlling workstations	(IT hardware power supply, IT hardware fan,KVM)	
1	Total Facility Power	x	x	x	x	x	x	x
2	IT Equipment Power				x	x	x	
3	Useful Work Produced				x			
4	Total Data Center Energy consumed over time	x	x	x	x	x	x	x
5	Total Power Load	x	x	x	x	x	x	x
6	Critical load				x	x	x	
7	Data Center Power Consumption	x	x	x	x	x	x	x
8	Total HW Power Consumption				x	x	x	
9	AC HW load						x	
10	DC HW compute load				x	x		
11	Number of Servers Running live applications				x			
12	Total Number of Servers Deployed				x			
13	Min. Number of Systems necessary to handle peak compute load				x			
14	Total number of systems deployed				x			
15	Power Drawn by Single hibernating Device				x	x	x	
16	Power Drawn by idle Device				x	x	x	
17	IT Equipment Load				x	x	x	
18	HVAC load		x					
19	HVAC Power		x					
20	Computer Power				x	x		
21	Computer load density				x	x		
22	Designed load density				x	x		
23	Performance/(space x watts)				x			
24	Network component's ratio of 'work performed' to energy consumed					x	x	
25	Actual IT load				x	x	x	
26	Total power consumtion	x	x	x	x	x	x	x
27	Facility capacity				x	x	x	
28	IT Utilization				x			
29	CPU Loading				x			
30	Total CPU							
31	Total Data Center Energy consumed over time	x	x	x	x	x	x	x
32	Number of I/O operations (or transactions) / energy (watts)				x	x		
33	Carbond dioxide emissions at the facility				x	x	x	
34	Useful work per usage of Watt				x	x	x	
35	Over temperature		x					
36	Allowable over temperature		x					
37	([[DELTA][T.sub.AHI]		x					
38	[DELTA][T.sub.Equip]]		x					

Findings:

Using the table, it is possible to identify the variables that have the same meaning but are named differently. Even if they might appear name-wise very diverse, the actual connection with the components is inalienable proofing otherwise. Certainly there is a chance of interpreting some of them in another way, but for the stability and accountability of this paper the assumption made is crucial. The affected variables are shown in the chart below:

Power Delivery components, cooling system components, IT infrastructure and lighting	IT Infrastructure	Server, Storage, RAM	Servers, storage, Telco, KVM
Total facility power Total Data Center Energy consumed over time Data Center Power Consumption Total Power Load Total Power Consumption	IT Equipment Power Critical load Total HW Power Consumption IT Equipment Load Actual IT load Facility Capacity	CPU Loading Useful Work Produced	Computer load density Computer Power Designed load density DC HW compute load
= effectively equal	= effectively equal	= effectively equal	= effectively equal

Table 9: Identical variable with different names of representation

3.7.2.3 Abstraction of the Variables

Here the variables are being transformed into variables in the mathematical sense i.e. "total facility power" becomes "A". The table visualizes this correlation. Each metric is being assigned a mathematical variable.

Variable	Assignment	Variable	Assignment
- Total facility power - Total Data Center Energy consumed over time - Data Center Power Consumption - Total Power Load - Total Power Consumption	**A**	**IT Energy Efficiency**	**Q**
- IT Equipment Power - Critical load - Total HW Power	**B**	**Total CPU Power**	**R**

Consumption - IT Equipment Load - Actual IT load - Facility Capacity			
- CPU Loading - Useful Work Produced	**C**	**Carbond dioxide emissions at the facility**	**S**
- Computer load density - Computer Power - Designed load density - DC HW compute load	**D**	**Useful work per usage of Watt**	**T**
AC HW load	**E**	**Over temperature**	**U**
Number of Servers Running live applications	**F**	**Allowable over temperature**	**V**
Total Number of Servers Deployed	**G**	**([[DELTA][T.sub.AHI]**	**W**
Min. Number of Systems necessary to handle peak compute load	**H**	**[DELTA][T.sub.Equip]]**	**X**
Total number of systems deployed	**I**	***EnergyBench***	**Y**
HVAC load	**J**	***Carbon footprint Environmental Impact***	**Z1**
HVAC Power	**K**	***Telecommunications Energy Efficiency Ratio (TEER)***	**Z2**
Facility Efficiency	**L**	***IOPS / Watt***	**Z3**
Facility Energy Efficiency	**M**	***SWaP***	**Z4**
Facility Utilization	**N**		
IT Asset Efficiency	**O**		
IT Utilization	**P**		

Table 10: Abstraction of variables

By doing so, duplications are being removed i.e. grouped together to a single mathematical variable and also further analysis is being enabled. The outcome of the analysis is an advanced pruning of the range of variables. It can be seen, that in fact multiple variables can be melt down to a single meaning. This will be the base of pointing out redundancies or dependencies respectively between the metrics in the next step.

3.7.2.4 Identification of Dependencies

As a part of the analysis of the metrics, it is necessary to identify redundant metrics to avoid duplication. The metrics are considered to be dependent, when they are using exactly the same type of variables. To find the dependencies among metrics, first all the variables available were plotted into a matrix and assigned mathematical variables.

For a thorough analysis, also the metrics need to be brought into a proper format. The next table shows the assignment of numbers to the metrics.

Metric	Number
PUE (Power UsageEffectiveness)	1
DCiE (DatacenterInfrastructureEfficiency)	2
DCeP (Data Center Energy Productivity)	3
SI-EER (Site Infrastructure Energy Efficiency Ratio)	4
SI-POM (Site Infrastructure Power Overhead Multiplier)	5
H-POM (IT Hardware Overhead Multiplier)	6
DH-UR (Deployed Hardware Utilization Ratio)	7
DH-UE (Deployed Hardware UtilizationEfficiency)	8
Ratio of IT Equipment to HVAC Load	10
Ratio of HVAC Power to Computer Power	11
Computer LoadDensity	12
EnergyBench	19
SWaP	23
CarbonfootprintEnvironmental Impact	20
Telecommunications Energy Efficiency Ratio (TEER)	21
CADE [Corporate Average Data Efficiency]	13
DCPE(Data center Performance Efficiency)	14
IOPS / Watt	22
Technology Carbonefficiency(TCE)	15
Data Center Energy Efficiency and Productivity Index (DC-EEP Index)	16
RackCooling Index (RCI)	17
Return Temperature Index (RTI)	18

Table 11: Assignment of numbers to metrics

At this point it is possible to carry out a proper evaluation of the dependencies. After having abstracted the variables and metrics, a matrix can be created. It is listing on the x-axe and y-axe all the variables, as shown in the table above. Almost all the formulas are composed of only two variables, so that they can be described using the two axes. PUE ("1") for example is composed of "A" and "B", and therefore a "1" is inserted in the matrix where the imaginary lines of "A" and "B" collides. All the metrics are inserted that way. An exception is "C.A.D.E.", which is composed of more variables. For this metric multiple entries exist. The reason can be illustrated as follows: "C.A.D.E" can be expressed by = Facility Efficiency * IT Asset Efficiency, which is one entry. Then, each of them is composed again of two variables, hence, another two entries, and so forth. For the other metrics it was done accordingly. Another peculiarity is the row "single". These are metrics that use only one single variable.

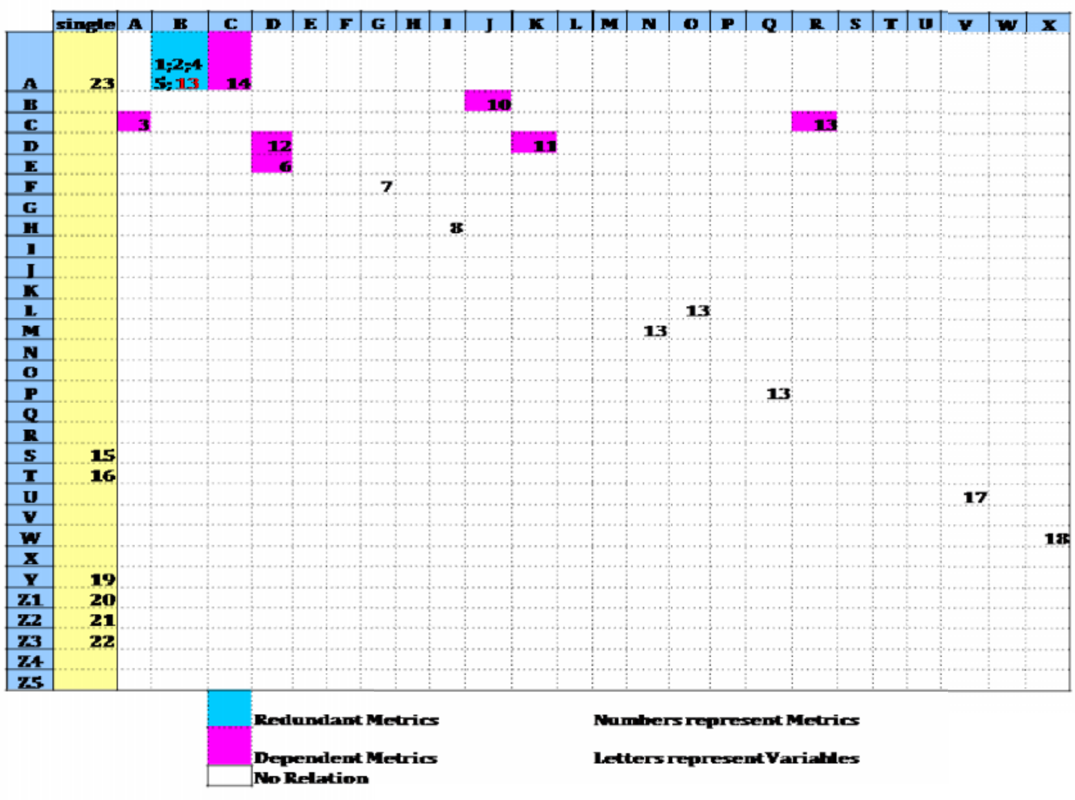

Figure20: Matrix view of dependency and redundancy metrics

Findings

The redundancies between the metrics are classified as Operational redundancy and Qualitative redundancy.

Operational redundancy occurs when the influencers of the metric are already a metric for datacenter assessment themselves and any change in the influencer (i.e. the metric) will simultaneously cause changes in the metric. There are two metrics, which have operational redundancy:

- **TCE:** Technology Carbon efficiency rate(TCE =PUE X Electricity Carbon emission rate)from the formula it is very clear that one of the influencer is PUE metric. So any changes in PUE metric will surely cause change in TCE
- **DC-EEP:** Data center Energy Efficiency and Productivity index (DC-EEP=IT-PEW x SI-EER)as explained above this metric too has one of the influencer, SI-EER, which is already a metric, which is used for datacenter assessment.

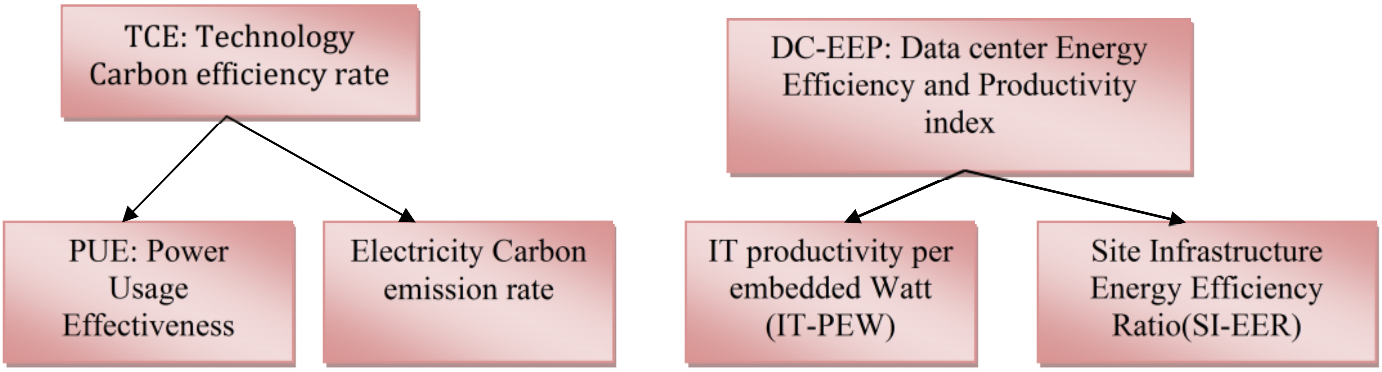

Figure 21 Operational Redundancy

The Qualitative redundancy occurs when the metrics use the same variables as influencers. Any change in the influencer will affect the relevant metric it is influencing. The basic criterion is to identify metrics, which are influenced by the same set of influencers. We have qualitative redundancy between the four metrics-PUE, DCiE, SI-EER, and SI-POM.

1. PUE: Power Usage Effectiveness (PUE = Total Facility Power/IT Equipment Power).
2. DCiE: Datacenter Infrastructure Efficiency (DCiE = 1/PUE = IT Equipment Power/Total Facility Power x 100%)
3. SI-EER: Site Infrastructure Energy Efficiency Ratio (Total Power Load / Critical Load)
4. SI-POM (Site Infrastructure Power Overhead Multiplier)(Data Center Power Cons. / Total Hardware Power Consumption)

The figure below represents qualitative redundancy among metrics

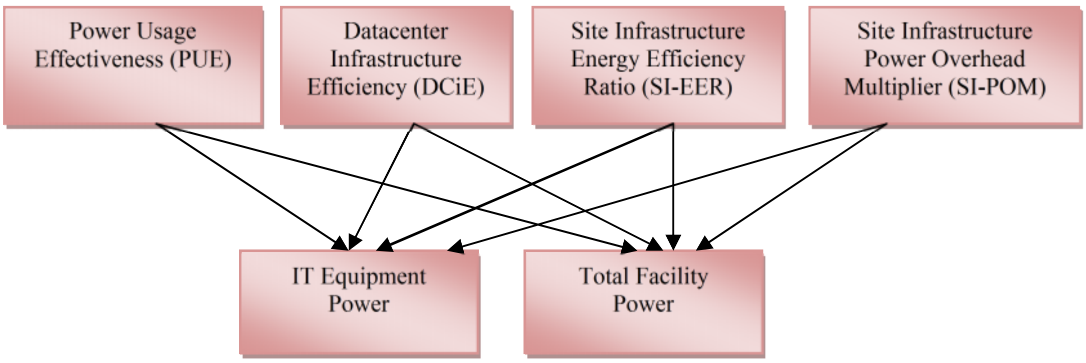

Figure 22 Qualitative Redundancy

These metrics are influenced by the influencers Total facility power and IT equipment power. Even though the use of influencers in each metric is different (Using the same variables but different formula for each metric), any change in the influencers will cause an equal impact on all the metrics it influences.

Thus now when summarizing both the operational redundancy and qualitative redundancy together we could clearly understand the combined effect. As said in qualitative redundancy if any change in either total facility power or in equipment power it would affect the metrics whichare influenced by these variables for their calculation. In return this change propagates to the metric whichhas the influencers as the metric which has already been affected by the changes caused by its influencers (i.e. total facility power or in equipment power). This concept is represented in the figure shown below

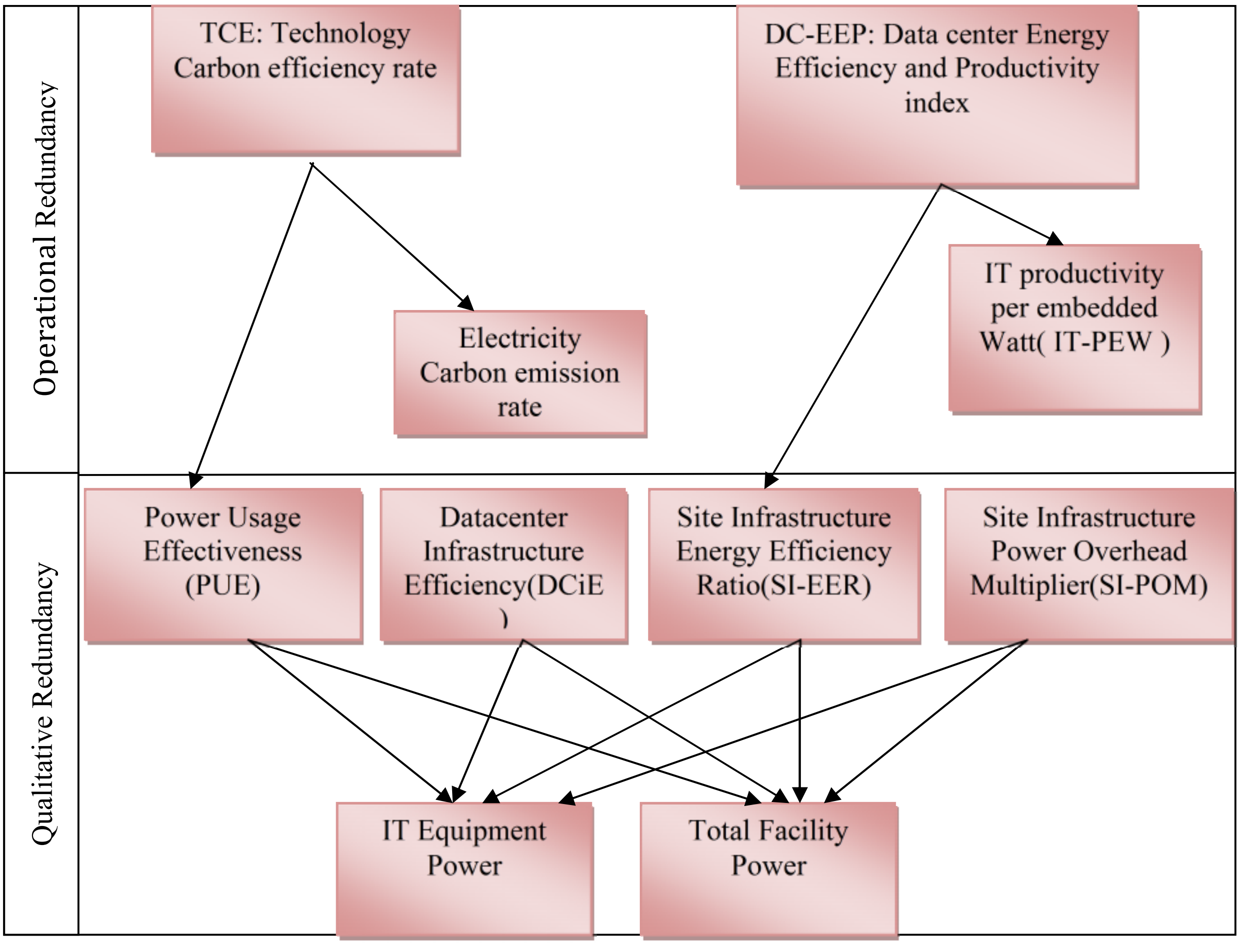

Figure 23 Summary of both operational and Qualitative redundancy

4 Tools

"DCIM (Data Center Infrastructure Management) – tools are evolving rapidly and will become a key part of a Data Center manager's arsenal during the next few years, providing valuable data needed to report on and improve energy efficiencies, identify potential infrastructure trouble spots and increase the effectiveness of capacity planning. To take advantage of the benefits as they evolve, I&O leaders should begin the DCIM evaluation process in 2010 and 2011."

- By Gartner, "Physical Resource Infrastructure Management is Evolving" (August 2008) and "DCIM – Going beyond IT" (March 2010)

IT leaders can invest their time and capital wisely by identifying IT's most energy-consuming assets, prioritize projects accordingly, and accurately quantify savings over time. The technology landscape for IT energy and environmental measurement is quite mature. IT organizations are taking a more active role in investing in these technologies."

- byForrester Research, "TechRadar For I&O Professionals: Green IT 1.0 Technologies, Q2 2009" (June 2009)

These quotations explain the current scenario within the software tools for Green IT- Industry. First of all, there is a rapid evolvement happening – as it appears with the metrics – that has gained an incredible pace. Second, the driver of this evolvement is the pure urge of efficiency, effectiveness and improvement analysis of Data Centers. It also makes clear that the technology for such venture is already available, since the gauges are very simple; data collection is made using wireless networks and web-based dashboards. Last but not least the programming of the software is no challenge anymore nowadays. Generally speaking, the tools are the mean of monitoring, which is crucial to save costs, to plan future capacity needs, to improve performance and utilization of existing equipment, and proactively manage power risks before they become disasters.

4.1 Presentation of the Tools

This chapter gives an overview of some important software tools, which are currently available on the market. The focus lies hereby on Green IT monitoring software. The suitability of tools will be verified based on their capability to satisfy the below two criteria

1. Monitoring / gathering rudimentary data about a Data Center

The software tool must be able to collect relevant data about the Data Center. For this it needs to be compatible with the components installed and act as a central knot where all the information runs together.

2. Calculating on that basis further energy / usage relevant indicators (metrics)

The software tool must include proper functions, either preinstalled or customizable that enables the calculation of all relevant metrics. Furthermore the dashboard needs to visualize the outputs in a clear and understandable manner.

These qualifications carry a very general character that does not fit tothe need of every Data Center independently of its set up. Hence list of Tools available are divided into 5 main areas. This grouping is necessary to give a better understanding of how the software can benefit within the individual's Data Center i.e. for some applications a simple Tool may serve the use.

The groupings at a glance

Special tools for Green IT

These Tools don't offer a complete monitoring or evaluation options, but given the right input data, they can be used to calculate a very limited set of metrics or at least visualize the outcome accordingly. They are specialized in the sense that they look only at a part of the Green IT field. Mostly they emerged at an earlier point of Data Center assessment and therefore don't imply such a holistic approach as newer outcomes.

Energy Management Tools

These Tools were developed mainly to assess the energy consumption in the Data Center. Some of them do also have a little extension to that, which does not suffice for a proper evaluation though. The configuration appears too specifically adapted to power assessment, so that if further features are needed, other tools shall be preferred.

Server and Network Management Tools

These Tools are the energy management tools that are specifically designed for server and network assessment. For the same reasons as before, they are grouped together.

Holistic Management Tools:

These Tools can be called the evolution of the first three types of tools i.e. the premium versions. They combine energy management, server and network management, cooling and other management tools in one, while providing advanced web-based visualization, too. For that reason “holistic” seems to be an appropriate description.

Holistic Management Tools combined with customized Hardware

These Tools combine the features of the latter type with the suitable hardware. The hardware ranges from specific gauges to intelligent PDUs or smart servers. They deliver a package that completes the picture of what is ongoing within the Data Center. So to say, they additionally provide all the equipment for monitoring the Data Centers components in terms of temperature, humidity and air streams.

4.1.1 Special Tools for Green IT

Dashboard of Sustainability

This software is freely accessible to the public. It was developed by the Consultative Group on Sustainable Development Indices (CGSDI). It is presenting complex relationships between economic, social and environmental issues in a very easy and understandable way. It was originally designed to meet the desire of citizens to have an insight of state-run institutions and their implications, for example not only on GDP growth, unemployment rate and inflation, but also on environmental issues. This is why the software is kept so simple; the normal citizens have to be able to interpret the dashboard sufficiently. They are enabled therefore to judge governmental performance. As can be seen in the figure below, the output is a simple pie chart based on three principles. The size of segment reflects the relative importance of the issue described by the indicator, the color codes signal relative performance, with Green meaning “good” and red meaning “bad”, a central circle, the Policy Performance Index (PPI), summarizes the information of the component indicators.[23]

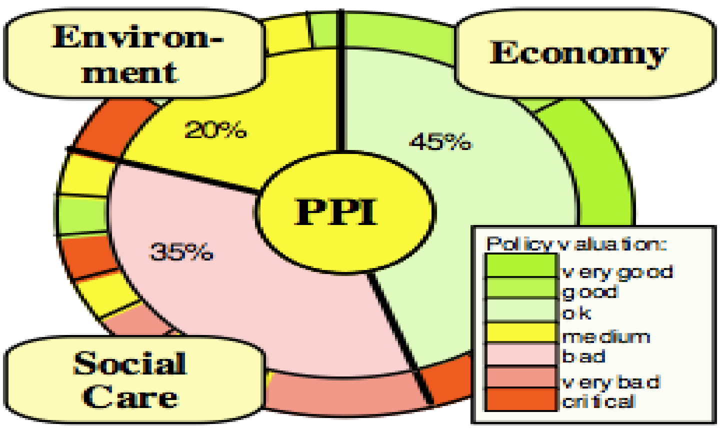

Figure 24 Dashboard representation

The dashboard software can be considered as visualization software for Green IT. Inserting a set of data it will provide a clear and easy chart. The use is therefore very limited.

EINSTEIN – Thermal Energy Optimization

It is a fast audit tool for thermal energy optimization of a process and further more a methodology that works out energy efficient solution for production process based renewable energy sources. It is supposed to lead to a significant reduction of the operating cost. The goal is to reduce the costs of energy and CO_2 emissions by fast and high quality thermal energy audits, improved competitiveness and saving for the company by a reduction of operating costs and finally also by a road map for realizing energy concepts with an economic consideration. The Einstein Toolkit consists of 6 elements: Data Acquisition and Analysis Module, Process Optimization Module**,** Heat Recovery Module**,** Energy Supply and Renewables Module**,** Evaluation Module**,** and Reporting Module. This process related software is certainly an important instrument of the Green IT.[24]

BEES (Building for Environmental and Economic Sustainability)

It is a tool that uses different techniques for selecting cost-effective, environmentally preferable products. It measures the environmental performance of producing products by using the life-cycle assessment approach specified in the ISO 14040 series of standards. It was developed by the NIST (National Institute of Standards and Technology).

The whole life cycle of the product is being analyzed, from raw material acquisition, manufacturing, transport, installment, use until recycling and waste handling. To evaluate the economical performance, the ASTM standard life-cycle cost method is used. Inter alia there is implied the cost of initial investment, replacement, operation, maintenance / repair and disposal. The different performances are merged into an overall performance. To quantify the input data, BEES is using science-based technical content. In other words, it is using over 500 material and energy flows from raw material extraction until product disposal. As the following sketch shows, the overall score is being calculated using a total environmental performance score and an economic performance score.[25]

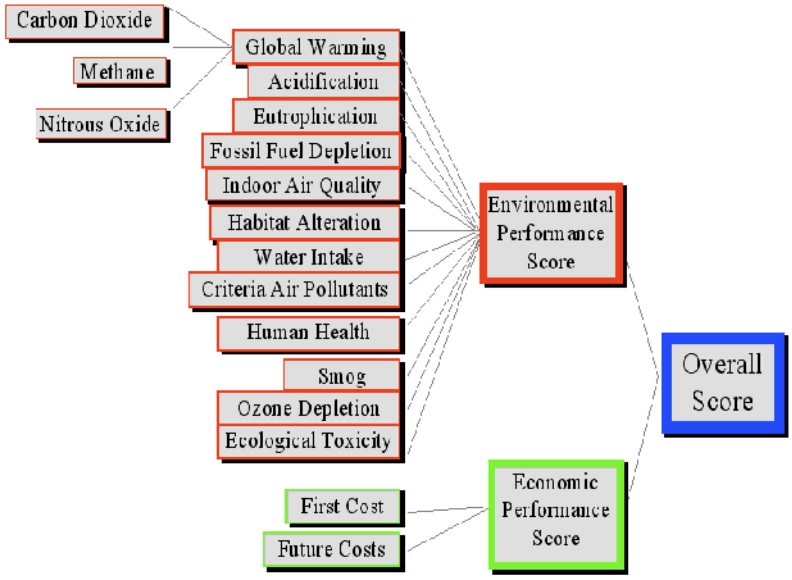

Figure 25BEES tool

Altiris Total Management Suite

It was developed specially to automate IT lifecycle and to enable IT organizations to manage, secure and support their IT assets. Reducing operational costs, increasing operational efficiencies, setting a base for future growth and aligning IT with business priorities. The key features are: integrated IT lifecycle management solution, a web-based console and IT process automation. The IT Management Suite includes key client and server management capabilities including provisioning, deployment, inventory, patch management, software updates, remote assistance, process automation, OS migrations, service desk, software packaging, and asset retirement.[26]

European Free Cooling Tool

This online tool has been developed to help Datacenter and facilities managers easily to determine how much free air-cooling and free evaporative cooling is available for individual Datacenters. Using country and city name, the tool allows users in Europe to input their specific variables - such as local energy costs, IT load, and facility load - to determine the energy savings for individual facilities (see screenshot below).[27]This software tool supplied by the Green Grid does help in fact to estimate thermo dynamical efficiency and saving possibilities.

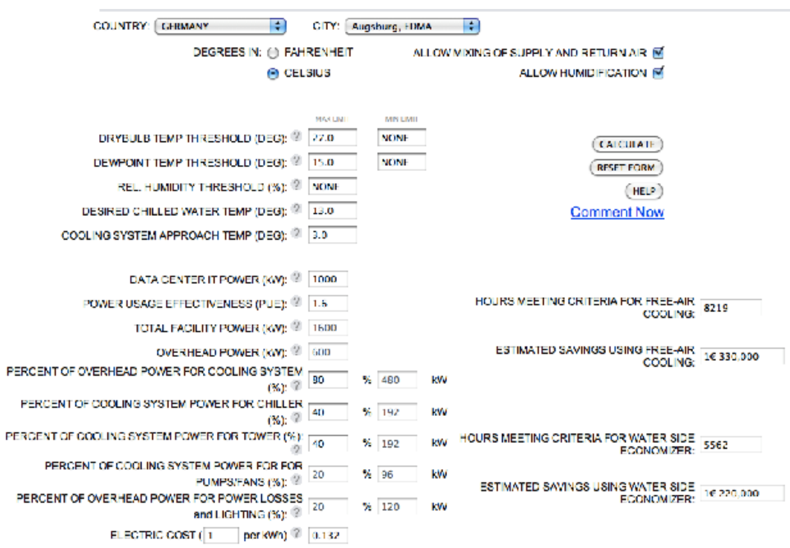

Figure 26 European free cooling tool

4.1.2 Energy Management Tools

DC Pro Software Tool Suite

It is used to identify and evaluate energy efficiency opportunities in data centers. It comprises two different tools, a profiling tool and a set of system assessment tools. They perform energy assessments on specific areas of a Data Center. Quick diagnosis of power consumption and of how power can be saved using the data center energy profiler (DC Pro) software tool suite. Basically it is giving a vast idea of where the energy is consumed, suggesting possibilities to safe power, and comparing all this with other sources of relevance. Upon provision of data of the users, DC Pro is creating a report that shows up potential savings. The input data is very crucial. The needed input data concerns the description of the facility, utility costs as well as other system information on IT, cooling, power, and on-site generation. The evaluation takes up to one hour.

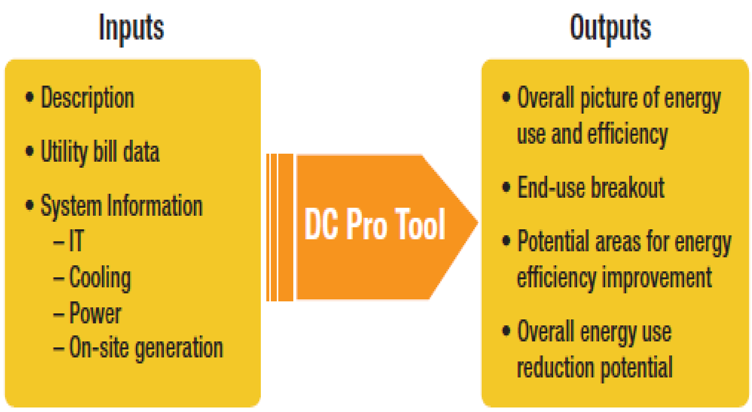

Figure 27DC pro tool

TheElectrical Systems Assessment Tool evaluates the electrical power chain of a data center. Namely it is concerning the transformers, generators, and uninterruptible power supply (UPS) and power distribution unit (PDU) devices. The possible save on energy estimated is based on typical practice and therefore the real value may differ according to the specific site set up.[28]

Power Configuration Efficiency Estimator

This software tool offered by the Green Grid presents efficiency related values. It is interactive and enables one to compare the efficiency of Data Center energy set ups build by pre- loaded or individually designated components (see chart below). It visualizes a curve, which illustrates nicely the efficiency of the component. It considers 6 different components: PSU, UPS, PDU, rectifier, converter and transformer. Further it is necessary to define the sub-type, vendor, model, output capacity as well as input and output voltage of the component. These details are necessary to estimate the wiring loss.[29]

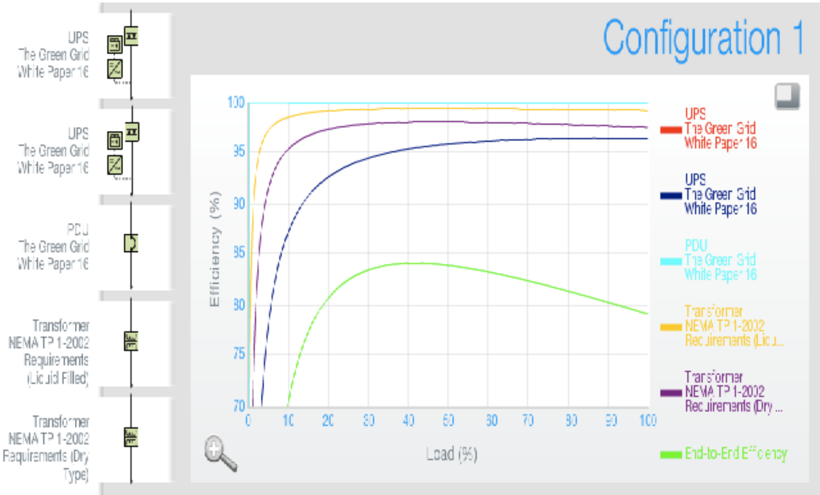

Figure 28 Power configuration Estimator tool

IBM Tivoli Monitoring for Energy Management

It is software to monitor, control and integrate energy with IT assets, the data center infrastructure and facilities assets. To connect these various dimensions it is enabling a comprehensive view of energy use in the Data Center. It also allows energy data to be viewed in the context of service management. Main output and benefit of the software is to provide to the company visibility in terms of an overview of all IT resources, services, IT and facility assets, energy costs and response times. It provides recommendations for reducing energy use, while maintaining service levels (controlling functions). It is building agility into operations through the ability to use automated policies for energy efficiency (automating functions). By integrating Tivoli with IT assets and facility building systems, assets can be monitored and managed for comprehensive energy, risk and service management.[30]

InfraStuxure Energy Efficiency

InfraStruxure Energy Efficiency is an intelligent Power Usage Effectiveness (PUE) analytics at subsystem level giving historical and also actual values. It helps to estimate the amount of energy needed to run the installed IT-equipment in comparison to the overall facility energy use. On a subsystem level it can give a micro- view of the efficiency as well as an idea as how to improve it respectively. A specialty is that the data about the subsystems can either be monitored or estimated. This is especially interesting for users who don't have a lot of gauges installed and/or just a few data sets available. The dashboard is web-based and it visualizes effectively the on goings on current and historical PUE. Furthermore it provides a cost analysis (even down to the subsystems). InfraStruxure Energy Efficiency is available via *"InfraStruxure Operations"*, which enables integrations with *"InfraStruxure Central"* and third-party enterprise systems.[31]

SentillaEngergy Manager for Data Center

Sentilla Energy Manager 3.0 delivers a holistic view of power consumption including all components within a Data Center and IT- facilities. It is a software-only enterprise management solution that measures, tracks and analyzes the entire data center's energy profile. It does not matter even if it is metered or not; it suggests improvements that are recommended to plan and manage Data Center operations. After all organizations are armed with a comprehensive picture of where, when and why power is used. At a glance it provides optimization of IT performance by better managing infrastructure and applications, gives inside based on real time processing, improves capacity planning and allows chargeback to allocate energy costs that belong to the in-fact-use by department.[32]

EnergyManager

The EnergyManager is an open source software platform. It enables Datacenter owners to monitor, graph and coordinate their Data Center Energy Consumption. EnergyManager is built on Cacti and RRDTool; they are the open source leaders in the fields of storing and graphing time series data. To measure the volts, amperes, real power and apparent power used by the Data Center (including servers, storage and networking equipment), it is utilizing the data centers existing power distribution equipment (SNMP). Energy Manager includes a fast "poller" to gather data from SNMP enabled PDU's. It accesses historical data from up to three years. The energy information is presented to authorized users using RRDTool's advanced graphing capabilities. All of this is wrapped into an intuitive, easy to use administrative interface that can scale to support hundreds of PDU's. It is a very basic and simple way to evaluate the PDUs, but no other than that.[33]

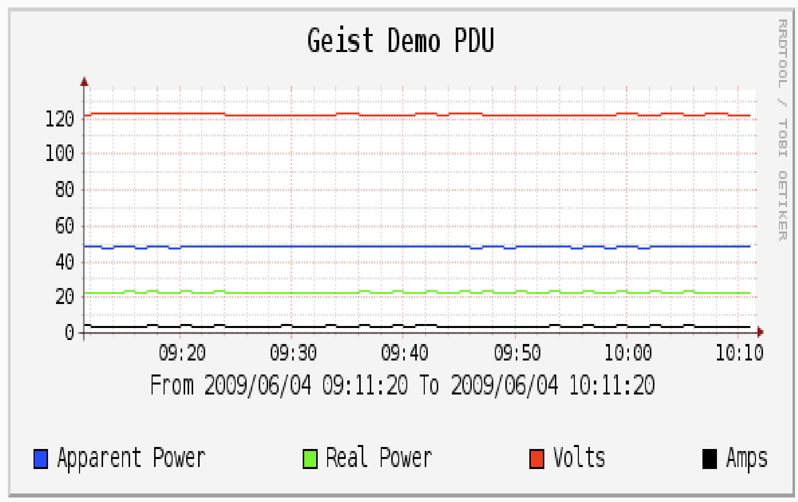

Figure: 29 Energy Manager tool

4.1.3 Server and Network Management Tools

BMC Blade Logic Server Automation Suite

BMC provides the highest uptime for business critical services by using policy-based server automation. More in detail, it delivers to the user the possibility to run "bare-metal" provisioning on new servers and re-provision operating systems on existing ones. Also to configure provisions, to patch, and manage heterogeneous servers depending on the chosen policy. Furthermore it gives compliance to meter and show compliance with internal as well as external standards and regulations. It uses virtualization to manage physical and virtual states taken by a merged management platform. Other features include BMC Service Automation Reporting and Analytics for Servers, which primarily is needed to improve support and decision making for managing complex configuration changes across servers. BMC Service Automation Reporting and Analytics is powerful software that extends the industry-leading BMC Blade Logic Operation Manager Suite with analytics, dashboards, and out-of-the box reporting capabilities. Based upon ITIL and COBIT frameworks, this reporting and analytics tool enables users to instantly translate data captured by BMC BladeLogic products into easy-to-use reports, thus helping business owners make intelligent decisions when it comes to operational, financial, and contractual IT requirements. Built-in reports provide actionable information around inventory tracking, audit results, compliance, change tracking, job activity/scheduling, patch management, provisioning, server usage, and user tracking. Built upon a rich data warehouse with dimensional modeling principles, this robust reporting tool provides solutions to complex reporting needs such as pivot tables, trending, and data correlation which goes well beyond traditional charts and graphs. [34]

Monitor Magic

It is monitoring pro-actively the network and servers, using pre-defined thresholds which are providing an early feedback on performance degradations and failures. It enables one to monitor servers, network and applications, and to archive events, to trend reports and performances. Due to growing networks and the mass of components connected with that expansion, it becomes more and more difficult to supervise what is really happening. Monitor Magic is in fact helping to manage this task by creating event logs, reports and does performance trending. The key benefits result in time savings, pro-active system management, agent less remote monitoring, powerful performance trending, dynamic reports and an open (plug-in) command interface.[35]

SNM – System and Network Monitor

It was developed out of the previous, much more simplified version called SICM. The SICM software is still valid for light employments focusing on the ease to use. Since SNM is implying all features of SICM while improving and expanding them, only SNM will be explained in the following. SNM is used as a tool for monitoring, graphical outputting and alerting of the capacity of computing devices and applications. The data is collected 24h and stored for later reference.[36]

Examples of how SNM can be applied to monitor systems and networks include:

System Monitoring / System Management (Unix/Linux/Windows)	Disk Space Memory CPU Processes Latency (ping) Network Interfaces
Network Monitoring / Network Management (Switches/Routers/Firewalls/Wireless)	Latency (ping) Network Interfaces Network Errors CPU (Cisco) Packet Accounting (Cisco)
Application Monitoring	TCP ports (HTTP, SMTP, FTP, Telnet, etc) MySQL Stats MS Exchange Stats DNS queries Web Pages Web Stats (Apache and IIS) build your own custom module
Networked Devices	Printers UPS, power Environment (Temperature, Humidity)

Figure 30 System and Network Monitor tool

Uptime Software

This platform is cross-functional and integrating various management software solutions that are supporting the management, measurement and monitoring. Main focus is to ensure global quality of service, enabling proactive IT, and immediately cutting costs. Main characteristics are: Monitoring multiple data centers, server monitoring and reporting, virtual server monitoring and reporting, cloud monitoring and reporting, server consolidation and virtualization, capacity planning and reporting, SLA monitoring and reporting, application monitoring and reporting, application transaction monitoring, proactive IT& outage avoidance.[37]

Nagios

Nagios is advanced software for monitoring and alerting that gives Datacenter owners the ability to get an early insight of their IT Infrastructure to prevent disasters. The features include a comprehensive IT infrastructure monitoring, visibility by providing a central view of the entire IT operations network and business processes, awareness by sending alerts to the supervisors, proactive planning by automating the process, integrated trending and capacity planning graphs, customizability, ease of use, multi-user access to web interface allowing stakeholders to view relevant infrastructure status, and extendable architecture.[38]

Open SMART

OpenSMART is an open source project. The software was created to monitor servers and software applications. OpenSMART is a rich featured monitoring and reporting tool, including ease of use by being web-based, predefined checks for application and system monitoring, ability to monitor HA cluster applications, alerting of supervisors (email / SMS), collection and ad-hoc reporting of many system figures like disk space or CPU consumption, checks for application monitoring report, and saving data in a database. This enables the administrators to get SLA reporting data and historical performance data.[39]

Big Brother / Big Sister Network Monitor

The Big Sister Network Monitor the open source complement to Big Brother. The software features network monitoring, process monitoring, device monitoring, system monitoring, application monitoring, event log monitoring, performance monitoring, service level and database monitoring. Furthermore the current network status can be viewed in real-time, notifications on alerts when problems occur in the system and generation of a history of status changes.[40]

4.1.4 Holistic Management Tools

CA EcoMeter

The CA ecoMeter is a part of the CA`secoSoftware solution. It was designed to process real-time data created in the data center. Furthermore it is providing information about energy use and environmental variables, also from historical data. Additionally the software is enabled to perform periodical calculations, for example PUE, and also to gather data via SNMP, Modbus and BACnet protocols. The dashboard interface can display geographical drill-downs, trending, alerts and alarms. Data retrieval points may be: PDUs, UPSs, and backup devices, generators, branch circuits, cooling/CRAC units, environmental variables (Temperature / humidity), building management systems, utilities (water/natural gas) and calculated data points (PUE, DCiE, device power etc.).Essentially CA ecoMeter has the capability to calculate and monitor both energy and IT activity. This is because it was designed not to just track a short-list of metrics, but to be adaptable in such way that any data value that is available from the hardware is available for polling and computations. Data can be collected by CA ecoMeter at frequent polling intervals and calculated either in-stream as part of the actual poll (often used if the variables are related to a single device) or post-poll (when data is coming from a variety of different devices). The data is then stored and available for historical reporting/analysis or follow-on calculations. Further, data regarding IT activity such as CPU, Memory, Disk activity, etc can be polled as well and used in calculations for creating any type of data center efficiency metrics.[41]

Modius Open Data

ModiusOpenData offers a complete data center monitoring and management solution for generating a single, real-time analysis of all data center infrastructure across the enterprise, including all major data centers, server rooms, branch offices, and IDF closets.Open Data monitors all power distribution, cooling and environmental sensor equipment from a single console, providing comprehensive operational intelligence for unified performance analysis and metrics.ModiusOpenData offers a range of next-generation performance analytics, including automated power efficiency reporting (PUE/DCiE), outage prevention and event correlation analysis, and capacity and energy forecasting. The solution works by capturing performance data continuously and natively from all mission-critical equipment, including IT devices, facilities equipment, and environmental monitoring solutions. As to be seen in the following screenshot, the dashboard is kept clearly laid out and showing the most important indicators.[42]

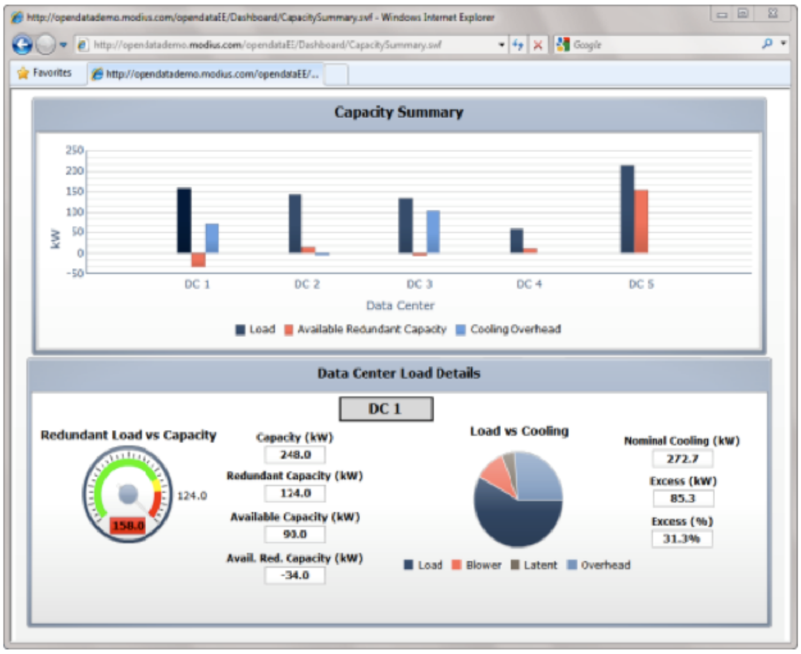

Figure 31 Modius Open Data tool

Osmius – Business- Oriented Enterprise Monitoring

Osmius is software that supervises heterogeneous systems using multi-platform agents that are distributed over a network. It is possible to control network elements (servers, database, temperature gauge) and to visualize the obtained information accordingly (in groups or charts), so that the user can access them via web consoles. The Osmius software is a holistic approach to data center assessment and beyond. It supports: Systems (servers, routers, devices, networks, racks), Applications (web apps, social, corporative CRM, ERPs, databases) Key Performance Indicators (business processes, HR efficiency, energy consumption) SLA (availability, response time, planned and unplanned downtimes) as well as Internet of the things (stock shares, climate values, pollution values in the neighborhood etc.) With the Osmius Web Console it is possible to manage the Osmius Infrastructure, to start/stop Agents, to deploy new ones and create proxies. Further it enables to define new SLAs, create new Instances and Services.TheOsmius Web Console provides also different Reports, Notification Systems (by default for example mail or SMS) and of course a Dashboard, even on the Iphone or Android mobile. There is a full functioning demo version accessible on the net (http://www.osmius.com/index.php/en/product/demo). The following screenshot shows the overview-dashboard of the osmius software. [43]

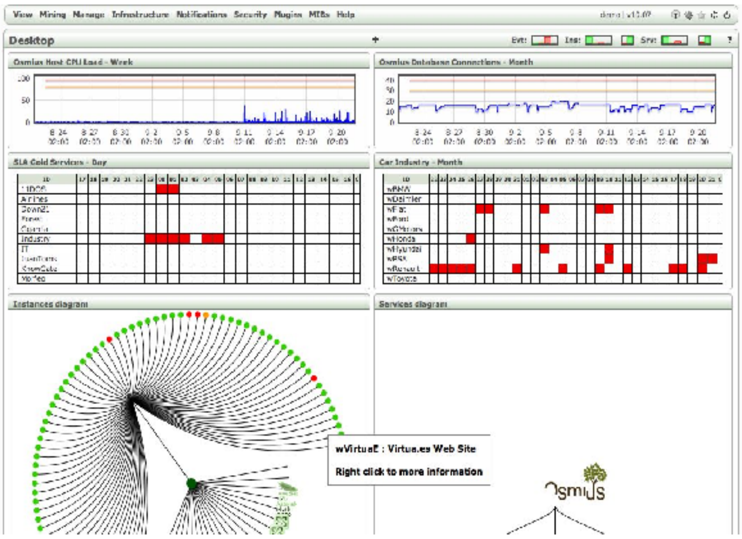

Figure 32 Osmius tool

Power Assure – Power Management for Data Centers

The Power Management for Data Centers Software was developed mainly for large enterprises and government agencies. Goal was to give them the ability to optimize their Data Center infrastructure with a variety of use cases: extending the life of the Data Center, decreasing Data Center power consumption, moving to “On Demand” computing, optimizing server placement, extending server consolidation and virtualization, leveragingGreen IT initiatives / rebates / CO_2 Trading, and decreasing test lab operating Costs.

Very interesting isthe fact, that with the introduction of Power Assure’s Dynamic Power Optimization software, the “Always On” model is no longer needed. Companies can now use Power Assure to automatically balance compute infrastructure with the actual demand. Power Assure’s technology determines the optimal capacity required for a given IT load and dynamically adjusts server availability in real time along with required cooling and facility resources. In effect, the paradigm shifts from servers that are “Always On” to “On Demand”, significantly increasing operational efficiency and decreasing on-going energy costs.[44]

Sentry Power Manager

Sentry Power Manager (SPM) provides a global view of all Sentry CDUs with the ability to view devices based on their temperature, humidity, current and device status. Besides managing and monitoring all alarm conditions, this information can also be used to provide reporting and trending information for display within SPM or can be integrated with the already existing Building Management System.

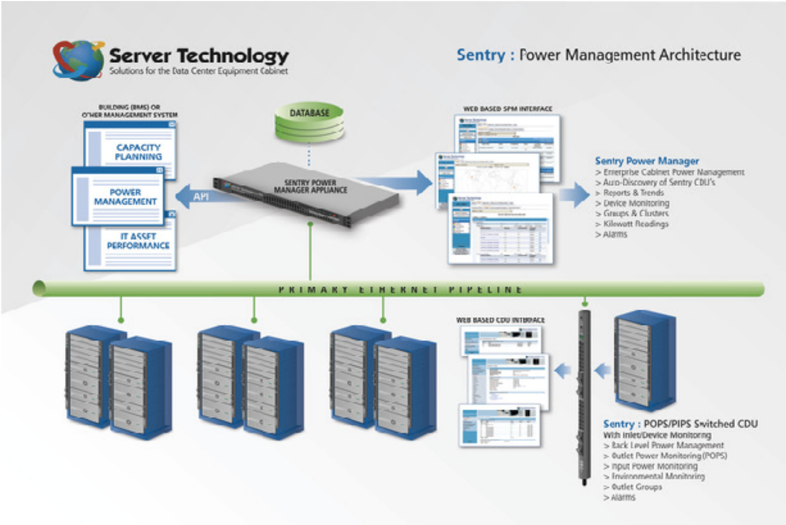

Figure 33: Server power manager tool

The Sentry Power Manger (SPM) is capable of providing a central interface to access multiple network monitored Sentry power distribution units, a Global view of all Sentry power distribution units (Cabinet PDUs) and the ability to view devices based on temperature, humidity, current and device status. Additionally it is able to control all networked Sentry cabinet power distribution units, the Sentry POPS (Per Outlet Power Sensing) Cabinet PDU on a per outlet basis.Then, power information including kW and kW-hour information for billing, power monitoring, trending and power reports as well as IT equipment power information that can be used to measure the efficiency in the Data Center for PUE and DCIE.[45]

Viridity - Energy Optimized Data Center

After launching Viridity`s energy resource management software, instantly ready to use data is made available about energy consumption related to the use of the applications. Further support is given on the homepage about specific analysis and action plans that are easily derived by the obtained data that assist the users on how to realize and quantify power consumption improvements. Data Center power draws, events triggering jobs, average server utilization, and number of underutilized servers are discovered extremely quickly. Furthermore hardware can be simply organized by a given visual Data Center layout including physical characteristics and server placement tools. Monitoring in a dynamic way the status of the Data Center is enabled; to see the power draw of the assets as well as their utilization and power consumption in general. Historical data gathered and reports generated are accessible down to the very detail.[46]

4.1.5 Holistic Software Management Tools combined with customized Hardware

ArchRock - the AREO Solution

ArchRock Energy Optimizer (AREO) is a suite of wireless environmental sensors, wireless sub- meters, IP routers, and web-based applications. They are all dedicated to Data Center energy optimization. With AREO, Data Center IT and facility managers can benefit from a real-time networked energy measurement and environmental monitoring solution. It is easy to integrate and manage within their existing IT infrastructure. At the same time it is delivering better visibility into the Data Centers' thermal and power- consumption profiles. AREO offers the Data Center manager the ability to closely track the thermal environment in time and space, to enable an increase of the global Data Center air temperature to save cooling costs while avoiding hot spots. Further it enables to utilize HVAC-Economizers with confidence gained by fine-grained temperature visibility. It is reporting in real time the detailed power usage at the circuit and rack level. Also an advantage is to deploy new server capacity with confidence, knowing the exact load on the circuit and rack PDUs at all times. Plus verifying the efficiency of the Data Center cooling system and properly matching plant load to rack-cooling load as well as identifying operational issues through Data Center thermal monitoring at any desired granularity in time and space.[47]

Figure 34 AREO tool

EpiSensor – SiCA Platform

SiCA for Data Center Monitoring is a complete solution for monitoring data center energy usage and environmental parameters to increase overall energy efficiency and generate detailed performance metrics, which can be compared across a corporate network of data centers.This allows facility managers to make informed energy efficiency decisions, bill customers based on energy consumption and identify areas of waste, which can dramatically reduce a data center's carbon footprint and increase profitability. Specialties are the Electricity Sub-Metering by Using EpiSensor's accurate and secure wireless nodes. Sensors can be deployed throughout multiple data centers to provide detailed sub-metering and environmental data.Environmental Monitoring Wireless temperature and humidity sensors can provide valuable data to identify thermal hotspots in the Data Center and prevent server and PDU overheating. It is based on Zigbee wireless technology, remotely accessible over the Management Software SiCA.[48]

PacketPower

PacketPower is designed to make it easy to understand what is driving the usage of electrical power. The distinctiveness is that PaketPower provides "smart" power cables that can measure the amount of energy that flows through them. This information is automatically and securely shared over a wireless network, providing a "plug and play" design that makes it easy to gather detailed power usage information. The system can monitor a few small appliances or hundreds of high-power circuits. Basically the system is composed of smart power cables that offer a flexible, simple to install and highly granular way of capturing power consumption and temperature information.Composed of EnvironmentalMonitors that provide an easy to install wireless monitoring solution for capturing detailed temperature and relative humidity data, a PowerManager software that makes it easy to create a facility power and heat map, set alerts, allocate energy costs and customize how to track energy usage across time, andDataHub software that provides an interface from the wireless monitoring devices to the existing Data Center monitoring software.[49]

SynapSoft - Data Center Monitoring and Energy Management

SynapSoft 5.0 is a wireless data center monitoring and energy management solution. It provides real time visibility, enhanced monitoring alerts and air mixing metrics, which lead to significant energy savings.SynapSoft 5.3 builds on the value and robustness of its predecessors and now enablesSynapSense Active Control, the latest energy saving solution. Data Center managers utilize this “SearchDataCenter.com 2009 Product of the Year” (Data Center Infrastructure category) to assess current operating conditions, identify opportunities and quantify efficiency improvements. SynapSense Active Control then saves up to 35% of cooling energy by continuously aligning cooling capacity to IT load. SynapSoft 5.3 provides real-time PUE and air mixing metrics to continuously measure energy efficiencyimprovements. LiveImagingmaps and movies depict actual changes in thermals, plenum pressure and relative humidity. The enhanced monitoring and powerful data analysis capabilities provided in SynapSoft 5.3 enable data center operators to continuously optimize power and cooling, with an incomparable ability to measure and track the impact of improvements.[50]

4.2 Ability of the Tools to calculate GPIs

In this section the earlier found Tools are again visualized in terms of their capability to calculate the metrics assessed in the second part of this paper. For the special Tools a classification is needed, because each of them uses different metrics. For the other Tools, there is no software-wise distinction made, since it can be assumed that each software Tool within a group, i.e. server and network management tools, are programmed to serve their specific field only. Again, there is a chance that one or another is capable to monitor / calculate some additional metric, but first it is not explicitly promoted by the developer and second it is very difficult to estimate customizability efforts of professional end-users. Consequently there is no ground for such valuation.

The following table presents the special Tools and their ability to represent / calculate certain metrics. It becomes clear that these Tools are not very much suitable for assessing the energy efficiency of Datacenters. Their ability to process a sufficient set of metrics is not given and does not even remotely meet the requirements of nowadays Datacenter assessments. Nevertheless, these are Tools that could be used to support decision- making in other fields of Green IT on one side, or could be used over and above other tools that lack this or another function to complement them on the other side. For example to estimating the carbon emission rates; many tools don't provide such features although they are gaining strict importance.

Special Tools for Green IT	**Metrics represented by the tools**
Dashboard of Sustainability	DCiE, ([RCI.sub.HI] and [RCI.sub.LO], RTI
EINSTEIN	DCiE
BEES (Building for Environmental and Economic Sustainability)	helps in selecting the building material, no metrics represented

Altiris Total Management Suite	estimates carbon emission
European Free Cooling Tool	determines how much free air-cooling and free evaporative cooling is available

Table 12 Special tools for Green IT

Further down the table13 represents the different Software Tool groupings and their ability of handling the various metrics. It is very important that we define each grouping.

The Energy Management Tools

These are tools that are able to process a fair set of metrics related to the energy consumption. They provide administrators valuable information about where and how efficient energy is being consumed, while giving them easy access and administration over web-based dashboards. Consequently these tools are sufficient to analyze Datacenters in terms of their efficiency "as is" and help to improve their performance (Greening). However, there exist a few drawbacks consisting in unsupervised black spots. First, the environmental impact is not ascertainable, i.e. TEER and TCE, which is supposed to be a must-have in the future. Second, they are not able to organize the IT equipment. Recall that a proper set-up and process automation improves efficiency enormously.

Server and Network Management Tools

These tools have became crucial in the last decade of being able to supervise the strongly increasing number of servers and machines, nowadays they provide a broad portfolio of various IT equipment management tools. During their development, energy efficiency was not a big issue as yet, so that they are hardly showing power usage monitoring abilities. Also environmental impact of Datacenters is not considered respectively. Naturally, the majority of the users are small to medium sized companies where the Datacenter holds only a supportive role for their business and is seen as a commodity to them. In such case these tools are absolutely satisfactory, since they assure availability and stability of the system without having an elevated impact on the company. In terms of supporting the Greening of the Datacenter, they don't adequately fit. Without a proper assessment of the energy consumption it is impossible to estimate inefficiencies. Contrariwise, if used combined with some easily accessible information i.e. total energy consumption or typical equipment consumptions, the professional user can obtain valuable information also on overall efficiencies.

Holistic Management Tools

These tools are the high-end software tools that emerged from a vigorously changed environment. Super-sized Datacenters, environmental awareness and skyrocketing energy costs crave for multi-functional tools that integrate all features in one. They provide monitoring of all components down to the very micro level detail (each fan and CPU) and in every aspect i.e. real time condition of each and every component, and advanced analysis functions (automated / customized), while some developers even started to reintegrate suitable intelligent hardware that works perfectly together with the software. Indispensable for nowadays challenges and in fact as can be seen in the table, all metrics can be processed and evaluated by these tools.

Metric	Energy Management Tools	Server and Network Management Tools	Holistic Management Tools
PUE (Power Usage Effectiveness)	x		x
DCiE (Datacenter Infrastructure Efficiency)	x		x
DCeP (Data Center Energy Productivity)			x
SI-EER (Site Infrastructure Energy Efficiency Ratio)	x		x
SI-POM (Site Infrastructure Power Overhead Multiplier)	x		x
H-POM (IT Hardware Overhead Multiplier)	x		x
DH-UR (Deployed Hardware Utilization Ratio)		x	x
DH-UE (Deployed Hardware Utilization Efficiency)		x	x
Energy-Save Metric	x		x
Ratio of IT Equipment to HVAC Load	x		x
Ratio of HVAC Power to Computer Power	x		x
Computer Load Density		x	x
Total Power Consumption	x		x
EnergyBench		x	x
SWaP		x	x
Carbon footprint Environmental Impact			x
TEER		x	x
CADE [Corporate Average Data Efficiency]			x
IOPS / Watt		x	x
Technology Carbon efficiency (TCE)		x	x
Rack Cooling Index (RCI)			x
Return temperature Index (RTI)			x

Table 13 Special tools for Green IT with the clusterization

5 Green Performance Indicators and Organizations

5.1 Investigational Approach – Modus Operandi

The goal of this final chapter is to compare the previous findings about the metrics and the tools with organizations' best practices that are actually running a Data Center. Motivation for such inquiry is the assumption, that there are only a few operators that actually use best practices at all. The knowledge diffusion concerning Datacenter efficiency assessment is expected to be very poor.

To obtain relevant information about this industry, two approaches were being used:

- First, contacts to Datacenter owners were established, directly by personal interviews and indirectly by sending out questionnaires.
- Second, these findings were substantiated through a careful collection of publicly available white papers and their subsequent evaluation.

For assuring consistency during the investigation and to focus only on paper-relevant issues, the questionnaire was used as code of practice i.e. it lay the base for the interviews. It is a consequent result of the previous three chapters and combines in a few pages the most significant topics of this paper.

5.2 The Questionnaire- Code of Practice

Preliminary Considerations

The questionnaire can be seen as a code of practice to assess what is the actual state of Datacenter assessment in the industry, and also as a guideline of investigation. In the following the single parts are explained so to point up the goals.

At a glance:

The document includes the parts Metrics, Tools and Components. They are vital to elaborate:

- Which are the most suitable tools to gather the necessary data for the metrics calculation.
- Which metrics do we need to assess qualitatively and quantitatively the efficiency of the Data Center.
- To what extent are the single components being monitored in terms of actual consumption / usage.

Part I - Tools

Questions:

a) Which software are you currently using to monitor your DC?

Please specify:

b) Do you know any other software tools that might be suitable for DC monitoring?

Please specify:

In measuring the performance of any characteristics of the datacenter tools are needed, which can make the laborious work easier, thus saving time, money and energy. There are a lot of varieties of software available to support the just mentioned issues. Depending upon the context of measurement the tools have to be chosen. It also helps in comparing the performance of one datacenter with the other. The tools may perform the role of comparison only, monitoring any or all performance characteristics and/or suggesting solutions for improvement. It is especially interesting to know about other possible tools that may be suitable for monitoring the datacenter with a similar architecture.

Part II – Metrics

Metrics are used for evaluating the performance of any specific characteristic of the datacenter. There exist a wide variety of metrics, which assess the performance characteristics of the datacenter at different levels. Below is a summarized list of the possible Green Performance Indicators, which can help to make the datacenter Greener. Further the importance of the monitored metrics for the specific organization is a major concern. Some might consider an actual vital metric as not important at all i.e. underestimating its importance. Additionally, if the metric is not being calculated / monitored at all, what might be the reason. Is it completely unknown to the Datacenter owner, does the metric not apply i.e. TCE because organization doesn't need to know environmental impact, or is it another reason i.e. monitoring technically not feasible. The following table shows these correlations and is also listing all the metrics of consideration. It is filled out randomly to show how it could look like as an exemplary manner.

Are these Metrics being monitored within your DC?	YES	NO	Importance (from 1 = not important to 10 = very important)	If NO, does not apply (NA) unknown (UK) other (specify)
PUE (Power Usage Effectiveness)	X		10	
DCiE (Datacenter Infrastructure Efficiency)	X		10	
DCeP (Data Center Energy Productivity)		X	-	Can not be monitored
SI-EER (Site Infrastructure Energy Efficiency Ratio)		X	-	UK
SI-POM (Site Infrastructure Power Overhead Multiplier)		X		UK
H-POM (IT Hardware Overhead Multiplier)		X		UK
DH-UR (Deployed Hardware Utilization Ratio)		X		UK
DH-UE (Deployed Hardware Utilization Efficiency)		X		UK
Energy-Save Metric		X		Can not be monitored
Ratio of IT Equipment to HVAC Load	X		8	
Ratio of HVAC Power to Computer Power		X	3	NA
Computer Load Density		X	3	NA
Total Power Consumption	X		10	
SWaP	X		7	
Carbon footprint Environmental Impact		X		NA
Telecommunications Energy Efficiency Ratio (TEER)		X		NA
CADE [Corporate Average Data Efficiency]		X		NA
DCPE(Data center Performance Efficiency)		X		UK
IOPS / Watt	X		2	
Technology Carbon efficiency(TCE)		X		NA
Data Center Energy Efficiency and Productivity Index (DC-EEP Index)		X		NA
Rack Cooling Index (RCI)	X		9	
Return temperature Index(RTI)	X		9	

Table 14 Monitoring of Metrics in the Datacenter (example)

Questions:

1. Are there any other metrics, which you are currently using, that are not listed above?

Please specify:

The wide range of the metrics listed is a combination, which assess the performance of the datacenter as a whole and also at each of its component level such as for cooling, networking, storage etc. With the answer to this question it can be assessed whether some metrics have been ignored that are in reality very useful for the assessment of the data center performance.

2. What is the frequency of data center assessment over the metrics monitored?

Please specify:

The frequency of datacenter assessment can give a clear picture about the company's commitment in trying to achieve efficiency improvements. Further, the social responsibility of the company to make the datacenter Greener can be understood.

4. In your opinion, are the RTI and RCI metric adequate for assessing the datacenter cooling units?

Please specify:

These metrics are used for assessing the air management within the datacenter. These metrics are widely used as the metrics for assessing the cooling units. The use is to know as per the company's opinion, are these indicators sufficient for assessing the performance of the cooling units in their datacenter or do they use other.

Part III - Component level

As explained earlier the datacenter can be monitored as a whole and also at its component level. It is crucial to know about the strategy of the assessment of the company at its component level. With the summary of components assessed by the company it is possible to find loopholes for poor efficiency, as it is mandatory to measure certain components to improve efficiency. It is strongly suggested that the company monitors those components. Hence again, the reason for not monitoring certain components is important.

Do you monitor or are you able to monitor the following components in your DC, concerning either energy consumption and/or usage?

DC Level	Component Level	Component being monitored YES / NO	If No, Does not apply (NA) Not installed (NI) Non relevant (NR)
Power Supply Units (PSU)	**UPS** (Uninteruptible Power Supply)	**Yes**	
	PSD (Power Supply Device)	**Yes**	
	PDU (Power Distribution Units)	**Yes**	
	Generators		**NA**
	Batteries		**NA**
	Cabling (Distribution Losses)		**NR**
	Switches		**NR**

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	transformers		**NR**
Cooling System Components	chillers	**Yes**	
	CRACs	**Yes**	
	direct expansion air handler DX units		**NA**
	pumps		**NR**
	cooling towers	**Yes**	
nodes to	compute		**NR**
	network		**NR**
	storage		**NR**
IT Infrastructure	servers (CPU, RAM)	**Yes**	
	storage devices	**Yes**	
	networking equipment	**Yes**	
	NOC (Network Operations Center) = monitoring / controling workstations	**Yes**	
	Sensor System / other Monitoring installments	**Yes**	
Other	data center lighting		**NR**

Table 15 Component level monitoring at the datacenter (example)

Additional Questions:

Are there any other components you are currently monitoring, which are not listed above?

Please specify:

To find if some components have been ignored that are very important for the assessment of the datacenter.

5.3 Findings

The metrics presented in this paper are complete and up to date. There were no additional metrics to be found. Contrariwise, most of the metrics are unknown to the organizations, because they don't monitor their data center with them at all (around 40%). Generally, a gap can be recognized between exactly these operators that never monitor their Data Center and those that monitor it up to real time. In between are only a few players that are monitoring every other week or month; sometimes only once a year.

With the investigation of the Datacenter energy efficiency assessment scenario in the present world, using the whitepapers and case studies it is found that DCiE, PUE, DCEP are the pioneer metrics in assessment. People consider these basic metrics as mandatory for monitoring. For the tools the outcome is multilayered. The respondents are using no other software tool than already presented in this paper. Organizations are using especially tools for monitoring their IT equipment in terms of processing performance, especially small to medium sized enterprises. For them energy expenses have only a subordinated impact on their business. Special tools for estimating the environmental impact find also no application. Only big companies as for example IBM, Google or Yahoo monitor according to their corporate responsibility policy such metrics. From the final report of the case studies, it is observed that as explained in this paper that people monitor every individual components and suggest changes to remove inefficient components. But there was no evidence about the metrics that they used in the assessment, since it was confidential in all the case study reports.

The list of the components is complete and does not need further granulation. Again, the components are monitored very well performance wise to avoid disasters and optimize usage, but not for energy consumption. Instead the typical power usages of the components are being drawn together.

5.3.1 The Outcome in short

For big Enterprises:

- All metrics monitored in the fields performance, energy consumption and environment
- High frequency, once a day or even up to real time
- Holistic software tools are used, sometimes in a package with smart hardware
- All components are monitored by intelligent hardware (high number of sensors)

For Small and Medium sized Enterprises:

- Power efficiency metrics are rarely used and if at all, only one or two
- The frequency of assessing power efficiency is very low (once a year, once a month)
- Environmental impact is not monitored at all
- Server and Network Management are the only tools used
- Some companies develop own assessment strategies
- The components are monitored very well in terms of performance, sometimes also in terms of energy consumption

These outcomes prove the state of the art and completeness of the metrics, tools and components presented within this paper, since no other than these could be found as currently being used.

5.3.2 Importance of specific Metrics

The following table shows the most commonly used, and at the same time most important metrics:

Metric
PUE
DCiE
CADE
HVAC / IT Power
RCI
RTI

Table 16 commonly used metrics

And in fact, it is possible to get a surprisingly clear picture of the Data center energy efficiency only by measuring these six Metrics. The efficiency assessment of the Data Center overall can be assessed by using PUE, DCiE or CADE, whereas the latter represents - by taking into account more variables than the others - a more complete metric. The metrics HVAC / IT Power, RCI and RTI are measuring the energy performance of the cooling units, which are main drivers for energy consumption. Consequently conclusions can be made to say if the Data Center, generally speaking, is efficient or not. For the major part of the enterprises this is fairly enough. On the other hand, this is only a macro approach that renders improvement actions difficult due to the lack of detailed information of the system.

Other metrics that are being monitored are **DCiE, SI-POM, H-POM, DH-UE, SWaP** and the **DC-EEP Index.** The metrics that measure the environmental impact does not play an important role to most of the operators as they are creating unperceived value to the businesses. Further, these metrics are neither demanded by the public nor mandatory to be monitored according to governmental legislations.

5.3.3 Suitability of the Tools

The tools proposed within this paper satisfy various needs asked by Datacenter operators from small to big. It turned out that the most commonly used software tools are the Server and Network Management Tools. As mentioned before, a lot of administrators do not yet feel the need to undertake great energy optimization actions. The pure organization and optimization of servers and their processes stands in their main focus, so to provide stability and reliability to the customers. In some cases the software tools are modified or extended in-house i.e. the very commonly used software "Nagios" can be customized to fulfill also some energy monitoring operations. However, the Server and Networking tools "off the shelf" are not suitable to assess the data center energy efficiency. Indeed they provide features that are indispensable for calculating variables that are included in other GPI- metrics, but without connecting the process relevant data with data about power usage, they don't have any benefit for improving energy efficiency. Another outcome is that some companies develop their very own software. This is the case merely for small enterprises that run Data Centers with the size of around 60 square meters. A lot of calculations are "hand-made", using rudimentary data created by a few meters in combination with typical power usage specifications and the electrical bill. Again, medium sized enterprises use the "customization-option", while big enterprises trust holistic solutions by advanced software tool providers.

5.3.4 The Component Level

On the component level the affected parts of a data center to be monitored is direct proportional to the extent of accuracy one wants to achieve. For calculating all the metrics, basically all components need to be equipped with gauges. Consequently there are a very high number of sensors needed to screen the environment and components respectively, in terms of Temperature, Humidity and Pressure (air stream). In reality, small and sometimes also medium sized enterprises use only the existing "on-board" meters that can't monitor all variables. Other, energy-aware companies though, successfully monitor their components down to the very sublevel, by using a distinct set of gauges, which are located throughout the whole data center. To get a rough idea, for a Data Center of the size of around 12000 square feet are approximately 670 environmental sensor needed. Usually they are taking advantage of wireless technology to facilitate integration with the software. Furthermore, a dense network of sensors allows a thorough overview over the data center's state, i.e. by visually capturing thermal maps in real time.

6 Conclusion

6.1 Shortcomings

Closing the gap

The metrics carry special relevance considering the "OEM – reality - GAP". The vendors usually have their own ways of assessing the hardware power consumption. The gap is the difference between the expected performance (OEM specifics) and the real (actual) performance. It can vary up to 35% or more. A commonly used term amongst the vendors is "typical" power specification. These are datasheets that are often not comparable to each and another, so that it is difficult to interpret them adequately. That is why there is a major importance for having metrics, that are able to monitor accurately the real "as is" power consumption and not to rely solely on OEM specifications.[51]

Measurement deficiencies

Every modern car or plane nowadays is equipped with various measuring instruments, according to which the pilot is adopting its way of flying or driving respectively. He knows how fast he is driving and how much fuel that is consuming. Using this data it is possible to adjust the right improvement measures. In about 20% of all Data Centers there are no measurement equipments at all for properly evaluating the efficiency. A poll raised by the Uptime Institute that illustrates the frequency of assessing the Data Center, underpins this thesis. In this poll, as much as 40% of the interviewed companies never monitor their facility (PEU/DCiE). Often, not even the total energy consumed in the data center is known to the owner, because it represents only a subset of the total power installed of the building. Proper gauges are crucial to measure temperature, humidity and air stream velocity to get specific data of what is happening in the Data Center. Installing a few monitoring gadgets and thereby being able to visualize and regulate (without doing any bigger investments), there are already savings of 10-20% obtainable.[52]

Standardization

The current situation concerning the Data Center Management Metrics standardization is signed by chaos. Though it is improving constantly due to the rising importance of a management efficiency benchmarking, still there are no internationally accredited standards. They are the basis for being able to compare Data Centers adequately, since bare numbers without any connection are more or less meaningless. Also they are needed – or will be needed - to release obligatory guidelines, similar to the "ISO-Standards" or a "CE- branding".

Additionally there are signs that Data Center owners will be obliged to verify their CO_2-emissions, which will be taxed consequently. They will need to be monitored equally around the globe to assure a fair treatment. In fact institutions as the Green Grid and Uptime Institute have already released some standards, but these are treated so far as welcome suggestions, not more. The main problem of defining standards is the scarce availability of data. As mentioned earlier, only a small percentage of Data Center owners do monitor their equipment, and even if they do, it is difficult to get that data centrally collected.

6.2 Suggestions

The suggestions are based on the previously elaborated findings and interpreted consequently by the authors.

Tools and their capability to monitor GPIs

To overcome shortcomings in efficiency assessment, companies can choose between three options: to extent features of existing tools by customization, to use additional monitoring software or to switch to holistic software tools.

In the following table possible combinations of software are suggested that are able to monitor all relevant GPIs. Tool 1 is monitoring all power consumptions, Tool 2 monitors all server and network performances and Tool 3 takes the environmental impact into account. The category is an indicator of how progressive the tools are in terms of preinstalled features, ease of use, visualization capabilities and customizability.

Tool 1 (SNP)	Tool 2 (Energy)	Tool 3 (Environment)	Category
Power Configuration Efficiency Estimator	Nagios	Altiris Management Suite	Simple
InfraStruxure Energy Efficiency	System and Network Monitor	Altiris Management Suite	Medium
IBM Tivoli Monitoring for Energy Management	BMC BladeLogic Server Automation Suite	European Free Cooling Tool	Advanced

Table 17 Clusterization of tool w.r.t the capability to monitor GPI

Selection of the Metrics

The following table shows different sets of metrics that are being suggested to provide knowledge creation for assessing satisfactory the energy efficiency of a Data Center. There are three variations; basic, advanced and professional. The basic set, containing only 4 metrics, is being suggested to small Data Center operators (floor area < 500 square meters), since they don't need a micro insight into their Data Center. The possible improvements in efficiency are too low. For medium sized Data Center operators (floor area 500 – 10000 square meter), the advanced set is assumed to be necessary. Professional monitoring should be done by big Data Centers (floor area > 10000 square meters), since there the relevance of environmental indicators is meant to be elevated.

Metric	Basic	Advanced	Professional
PUE or DCiE or CADE	+	+	+
HVAC / IT Power	+	+	+
RCI	+	+	+
RTI	+	+	+
DCeP		+	+
SI-EER		+	+
H-POM		+	+
DH-UR or DH-UE		+	+
TEER			+
TCE			+
DC-EEP			+

Table18 Selection of metrics

6.3 Outlook

Standardized performance measurement for data centers

Until now there is no standardized performance measurement for data centers. There are a lot of metrics developed by different Green Initiative organizations. The focus will be on harmonizing the monitoring of datacenters globally.

Holistic data center management

Further development will be real-time monitoring, which will allow organizations to immediately understand the relationship between space, power and cooling resources and react quickly to changes in the environment.

Green Metrics

Due to the public awareness of global warming and therefore the need to reduce the carbon footprint, companies will start to monitor more metrics that concern the environmental impact and sustainability.

Awareness to monitor the Data center

Lot of companies don't monitor at all, but as the cost for energy is increasing, the companies will have to monitor their datacenters to be more cost efficient. Also large number of companies will become member of Green initiatives and will support Green IT.

Holistic solutions for SMEs

Datacenter monitoring will become inevitable irrespective of the size of the enterprise. Hence it will pave the way to have very efficient software that monitors everything and an intelligent hardware that supports Datacenter monitoring also for smaller businesses.

Emerging of consultancy companies for Green IT

Going Green has become inevitable for any company to maintain its corporate image and also to have loyal customers. Because customers nowadays are well aware of Green IT. This has given rise to the concept of creation of consultancy companies whose only duty will be to support the client organization in Green IT.

Open architecture for future datacenters

As explained in previous chapter because of the improvement in technology and the advancement in ICT, the demand for more capacity of the datacenter is surely unavoidable. Hence, not only flexible design to accommodate future demand is sufficient, but also flexibility in subsequent monitoring competence should be made available. Hence, there will be open architecture available that can grow on demand.

Commoditization of datacenter technologies

With the increased awareness of the Green IT and the demand to have data center technologies that are energy efficient, these technologies will become a commodity for all companies in the future. Similar to how ICT has become a commodity now for all companies in other areas.

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