Smart City Cluster Collaboration

Existing Data Centres energy metrics – Task 1

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Document Change History

Vers.	Date	Author	Description
0.5	31.01.2014	GEYSER: TUC	First document draft
0.8	18.02.2014	GEYSER: TUC, SiLO RenewIT: IREC CoolEmAll: IREC DC4Cities : ENEA, GNF GreenDataNet: Eaton Industries, ICTroom, Credit Suisse Dolfin: UCL	Second document draft including contribution from 6 cluster projects
0.96	25.02.2014	GEYSER: TUC All4Green: Innowerk-IT GreenDataNet: Eaton Industries GENIC : TUE	Almost final version of the document containing the contribution of 8 cluster partners.
1.0	28.02.2014	GEYSER: TUC Dolfin: UCL DC4Cities: GNF	Final version of the document

Contents

1. Introduction

This document is a common deliverable of the Smart City Cluster of projects which includes the following projects: DC4Cites, DOLFIN, GEYSER, GENIC, RenewIT, GreenDataNet, All4Green and CoolEmAll.

The scope of this document is to present a consolidated list of existing data center related energy measurements and metrics representative for all parameters monitored by the projects part of the *Smart city cluster collaboration*.

Chapter 2 presents a classification of the energy metrics and Chapter 3 presents the consolidated list of energy metrics.

The document was continuously updated and consolidated based on the input provided by cluster partners who are working on *Task 1 - Identify existing metrics*. The consolidated version of the document will be used as a baseline for *Task 2 - Analyse the consolidated list of metrics and methodologies and determine their limitations and weak points*.

2. Metrics Classification

Table 1 presents the metrics, classified by the data center categories of parameters that the projects part of the Smart City cluster are planning to monitor. The assessment methodology for these metrics is detailed in the next chapter.

Table 1. Overview of identified data center metrics (click on the indicator name for assessment methodology details)

Indicator Name	Classification Level											
	Energy / power consumption (loads)						Energy produced locally	Heat recovered	Power shifting	CO2 emissions	Performance	
	IT	Cooling	UPS	Transformer	Lighting	Building					Economic performance	Applications Performance
CADE	☑	☑	☑	☑	☑		☑	☑				
PUE	☑	☑	☑	☑	☑							
DCIE	☑	☑	☑	☑	☑							
CPE	☑	☑	☑	☑	☑							
DCeP	☑	☑	☑	☑	☑							☑
DCU	☑											
ScE	☑											
DCcE	☑											

Indicator Name	Classification Level											
	Energy / power consumption (loads)						Energy produced locally	Heat recovered	Power shifting	CO_2 emissions	Performance	
	IT	Cooling	UPS	Transformer	Lighting	Building					Economic performance	Applications Performance
DCPD	☑					☑						
DCD	☑					☑						
SwaP	☑											
Useful Work	☑											
$Productivity_{DC}$	☑											
TPS/Watt	☑											☑
DH-UR	☑											
DH-UE	☑											
SI-POM	☑	☑	☑	☑	☑							
H-POM	☑	☑	☑	☑	☑							
U_{server}	☑											
$U_{network}$	☑											
$U_{storage}$	☑											
THD	☑	☑	☑	☑								
CUE	☑									☑		
CEB	☑						☑			☑		
WUE	☑									☑		
ERF	☑	☑	☑	☑	☑			☑				
ERE	☑	☑	☑	☑	☑			☑				
CEF	☑	☑	☑	☑						☑		
CIUD	☑									☑		
GPUE	☑	☑	☑	☑						☑		
PAR4	☑											☑
Global KPI of Energy Efficiency	☑	☑	☑	☑	☑	☑	☑	☑	☑			
DPPE	☑	☑	☑	☑	☑	☑	☑			☑		
ITUE	☑											

Indicator Name	Classification Level											
	Energy / power consumption (loads)						Energy produced locally	Heat recovered	Power shifting	CO2 emissions	Performance	
	IT	Cooling	UPS	Transformer	Lighting	Building					Economic performance	Applications Performance
TUE	☑	☑	☑	☑	☑							
DC FVER	☑										☑	☑
pPUE	☑	☑	☑	☑	☑							
ITEU	☑										☑	☑
ITEE	☑										☑	☑
KPI_{EC}	☑	☑	☑	☑	☑	☑	☑				☑	
KPI_{TE}	☑	☑	☑	☑	☑	☑	☑			☑		
KPI_{REUSE}	☑	☑	☑	☑	☑	☑		☑				
KPI_{REN}	☑	☑	☑	☑	☑	☑				☑		
KPI_{GP}	☑	☑	☑	☑	☑	☑					☑	
CCF	☑											
DCMM	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
Code of Conduct	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
PSRR	☑											
Data Centre Measurement, Calculation and Evaluation Methodology (DOLFIN)	☑	☑	☑	☑	☑	☑	☑	☑				☑
Grid Efficiency (All4Green Metric)	☑	☑	☑	☑			☑					
Energy Consumed by Service (All4Green Metric)	☑											☑
Energy saving vs. Quality of service (All4Green Metric)	☑											☑
Maximum and Minimum Site Energy Saving (All4Green Metric)	☑	☑										
GEC	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑		
MHz/Watt	☑											
Bandwidth/Watt	☑											

Indicator Name	Classification Level											
	Energy / power consumption (loads)						Energy produced locally	Heat recovered	Power shifting	CO2 emissions	Performance	
	IT	Cooling	UPS	Transformer	Lighting	Building					Economic performance	Applications Performance
StorageCapacity/Watt	☑											
IOPS/Watt	☑											
COP		☑										
EER		☑										
SEER		☑										
$Im_{DC,Temp}$		☑						☑				
HVAC Effectiveness		☑										
RCI		☑										
CSE		☑										
AEU		☑										
WEU		☑										
AE		☑										
Flow Indicators		☑										
CSS		☑										
RTI		☑										
RHI		☑										
SHI		☑										
DC Recovery Phase (All4Green Metric)		☑										
RHD		☑										
BTU/h		☑										
Data Center Temperature (◦C)		☑										
UPS Load Factor			☑									
UPS System Efficiency			☑									
UPS Usage			☑									
Load match and Grid Interaction				☑	☑	☑	☑	☑	☑			

Indicator Name	Classification Level											
	Energy / power consumption (loads)						Energy produced locally	Heat recovered	Power shifting	CO2 emissions	Performance	
	IT	Cooling	UPS	Transformer	Lighting	Building					Economic performance	Applications Performance
Lighting Density					☑	☑						
Building Heat Loss						☑		☑				
Weighted energy Balance in Data Centres							☑	☑	☑			
Carbon Credit										☑	☑	
Nuclear Emissions (All4Green Metric)										☑		
CO2 Emissions (All4Green Metric)										☑		
TCO											☑	
RoGI											☑	
Return on Investment of All4Green for the Energy Supplier (All4Green Metric)											☑	
Return on Investment of All4Green for the Data Centre (All4Green Metric)											☑	
GreenSDA and GreenSLA (All4Green Metric)											☑	
Energy cost / price											☑	

3. Energy Metrics

The following sections provide a high-level description of the most common metrics that are candidates for use during next work period the Smart City cluster of projects.

3.1. IT - energy / power consumption (loads)

3.1.1. Corporate Average Data Center Efficiency (CADE)

Proposed by: McKinsey & Uptime Institute[1]
Measures: Overall energy efficiency of an organization's data centers (organization energy footprint).
Measuring unit: unit-less (%)
Calculation Method:

$$CADE = Facility\ Efficiency * IT\ Efficiency$$

$$Facility\ Efficiency = Facility\ Energy\ Efficiency\ \% * Facility\ Utilization\ \%$$

$$IT\ Efficiency = IT\ Energy\ Efficiency\ \% * IT\ Utilization\ \%$$

where:

- $Facility\ Energy\ Efficiency\ \%$ – IT power consumption divided by total power consumed by the DC
- $Facility\ Utilization\ \%$ – actual IT power consumption (servers, storage devices and networking equipment) divided by facility power capacity
- $IT\ Utilization\ \%$ – average CPU, network and storage utilization percent
- $I\quad Energy\ Efficiency\ \%$ – to be assessed based on future energy efficiency metrics

3.1.2. Power Usage Effectiveness (PUE)

Proposed by: Green Grid[2]
Measures: How much power is used by the IT Equipment in contrast to Facility
Measuring unit: unit-less (no.)
Calculation Method:

$$PUE = \frac{Total\ Facility\ Power}{IT\ Equipment\ Power}$$

Comments regarding PUE (as Power-based metric)

[1] http://www.ecobaun.com/images/Revolutionizing_Data_Center_Efficiency.pdf
[2] http://www.thegreengrid.org/~/media/WhitePapers/WP49-PUE%20A%20Comprehensive%20Examination%20of%20the%20Metric_v6.pdf?lang=en

To solve inconsistencies, a group of global leaders has been meeting regularly to agree on standard approaches and reporting conventions for key energy efficiency metrics[3]. In consequence of that, four categories of PUE have been defined, PUE_0 being the current category for the first PUE definition. In fact, PUE_0 is still a demand based calculation representing the peak load during a 12-month measurement period[4].

$$PUE_0 = \frac{P_{DC}\,[W]}{P_{UPS}[W]} = [\emptyset]$$

The IT power is represented by the demand reading of the UPS system output or sum of outputs if more than one UPS system is installed, as measured during peak IT equipment utilisation.

The most recent activities of The Green Grid about metrics focus the nomenclature of PUE on the point of measurement, data measurement frequency and averaging period[5]. The PUE_0, that corresponds to a power-based metrics, an instantaneous measurement on UPS point without averaging value, should be named as PUE_{L1}.

Comments regarding PUE (as Energy-based metric)

Being the PUE initially introduced as instantaneous value based on power measurements, some efforts were done by the Data Centre Efficiency Task Force to extend PUE to energy usage effectiveness in data centre facilities by defining $PUE_{1\text{-}3}$ depending on the measurement point and respectively at the UPS, PDU and single IT equipment [21]. The methodologies for calculating the PUE are in the cited paper.

$$PUE_1 = \frac{E_{DC}[Wh]}{E_{UPS}[Wh]} = [\emptyset]$$

$$PUE_2 = \frac{E_{DC}[Wh]}{E_{PDU}[Wh]} = [\emptyset]$$

$$PUE_3 = \frac{E_{DC}[Wh]}{E_{IT}[Wh]} = [\emptyset]$$

PUE Scalability

This concept has been recently developed by The Green Grid association. This is not a simple metric if not a complete statistical analysis of PUE values recorded in a certain period of time. The main objective of PUE Scalability is to provide information about how the total load of a data centre can be adapted to variations of IT load. In an optimally designed data centre the infrastructure should (ideally) proportionally scale total power with changes in IT power loads.

[3] Global Metrics Harmonization Task Force, "Harmonizing Global Metrics for Data Center Energy Efficiency. Global Taskforce Reaches Agreement on Measurement Protocols for PUE Continues Discussion of Additional Energy Efficiency Metrics," 2011.

[4] Data Center Efficiency Task Force, "Recommendations for Measuring and Reporting Overall Data Center Efficiency. Version 2 – Measuring PUE for Data Centers," 2011.

[5] The Green Grid, "White paper #49. PUE (TM): A comprehensive examination of the metric. Confidential Report," 2012

The metric is defined as:

$$PUE\ Scalability\ = \frac{m_{actual}}{m_{PUE}} = [\emptyset]$$

The slope of proportional PUE Scalability is calculated as:

$$m_{PUE} = \frac{mean(P_{DC})}{mean(P_{IT})}$$

The slope of actual PUE Scalability is calculated as:

$$m_{actual} = \frac{\left(N \cdot \sum_{i=1}^{N}\left(P_{IT}(i) \cdot P_{DC}(i)\right)\right) - \left(\left(\sum_{i=1}^{N} P_{IT}(i)\right) \cdot \left(\sum_{i=1}^{N} P_{DC}(i)\right)\right)}{\left(N \cdot \sum_{i=1}^{N}\left(P_{IT}(i)\right)^2\right) - \left(\sum_{i=1}^{N} P_{IT}(i)\right)^2} = [\emptyset]$$

The maximum value of PUE Scalability (ideal data centre) is 100 %.

Equation for PUE for GOOGLE data centers

$$PUE = \frac{ESIS + EITS + ETX + EHV + ELV + EF}{EITS - ECRAC - EUPS - ELV + ENet1}$$

ESIS: Energy consumption for supporting infrastructure power substations feeding the cooling plant, lighting, office space, and some network equipment
EITS: Energy consumption for IT power substations feeding servers, network, storage, and computer room air conditioners (CRACs)
ETX: Medium and high voltage transformer losses
EHV: High voltage cable losses
ELV: Low voltage cable losses
EF: Energy consumption from on-site fuels including natural gas & fuel oils
ECRAC: CRAC energy consumption
EUPS: Energy loss at uninterruptible power supplies (UPSes) which feed servers, network, and storage equipment
*ENet*1: Network room energy fed from type 1 unit substitution

3.1.3. Data Center Infrastructure Efficiency (DCIE)

Proposed by: Green Grid[6]

[6] https://www.thegreengrid.org/Global/Content/white-papers/DCiE-Detailed-Analysis

Measures: The energy usage and efficiency of the infrastructure equipment supporting IT equipment within a data center
Measuring unit: unit-less (no.)
Calculation Method:

$$DCIE = \frac{1}{PUE} = \frac{IT\ Equipment\ Power}{Total\ Facility\ Power}$$

3.1.4. Compute Power Efficiency (CPE)

Proposed by: Green Grid[7]
Measures: The efficiency of a data center. Usually not all electrical power delivered to the IT Equipment it is used by that equipment for useful work.
Measuring unit: unit-less (no.)
Calculation Method:

$$CPE = \frac{IT\ Equipment\ Utilization}{PUE} = \frac{IT\ Equipment\ Utilization * IT\ Equipment\ Power}{Total\ Facility\ Power}$$

3.1.5. Data Center Energy Productivity (DCeP)

Proposed by: Green Grid[4]
Measures: Overall work product of a data center per unit of energy expended to produce this work
Measuring unit: Normalized Tasks / kWh
Calculation Method:

$$DCeP = \frac{Useful\ Work\ Produced}{Total\ Energy\ Consumed\ by\ the\ Data\ Center}$$

$$Useful\ Work\ Produced = \sum_{i=1}^{M} V_i * U_i(t,T) * T_i$$

where:

- M - the number of tasks initiated during the assessment window

[7] http://www.thegreengrid.org/~/media/WhitePapers/WhitePaper13FrameworkforDataCenterEnergyProductivity5908.ashx?lang=en

- V_i - normalization factor that allows the tasks to be summed numerically
- $U_i(t, T)$ - time-based utility function for each task, where the parameter t is elapsed time from initiation to completion of the task, and t is the absolute time of completion of the task
- T_i - 1 if task i completes during the assessment window, and 0 otherwise

3.1.6. Data Centre Utilisation (DCU)

Proposed by: Green Grid[8]
Measures: The amount of power drawn by the IT equipment relative to the actual capacity of the data centre.
Measuring unit: unit-less (no.)
Calculation Method:

$$DCU = \frac{\mathrm{P_{IT}}\ [\mathrm{W}]}{\mathrm{P_{IT,rated}}\ [\mathrm{W}]} = [\emptyset]$$

Where, $P_{IT,rated}$ is the rated power capacity to hold the IT equipment in the Data Centre, [W].

3.1.7. Server Compute Efficiency (ScE)

Proposed by: Green Grid[9]
Measures: Percentage of servers doing “useful work” meaning the servers having active primary services
Measuring unit: unit-less (%)
Calculation Method: summing the number of samples where the server is found to be providing primary services (p) and dividing this by the total number of samples (n) taken over that time period and multiplying by 100

$$ScE = \frac{\sum_{i=1}^{n} p_i}{n} * 100$$

p is a server providing active primary services and n is the number of server from the data center used in the sample**.**
Criteria to determine a *server p*:

- The average amount of CPU utilization attributable to primary services (total average CPU utilization minus average CPU utilization from secondary and tertiary services) is above a designated threshold, such as 10%, which has proven to be an effective choice.
- The amount of I/O attributable to primary services (total I/O minus I/O from secondary and tertiary services) is above a particular threshold; experience has shown 500Kb/sec to be a good threshold.

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[8] The Green Grid, “Productivity Indicator,” 2008
[9] http://www.thegreengrid.org/~/media/WhitePapers/DCcE_White_Paper_Final.pdf?lang=en

- A primary services process (not a secondary or tertiary service) has received an incoming session based connection request.
- There has been an interactive logon to the server.

3.1.8. Data Center Compute Efficiency (DCcE)

Proposed by: Green Grid[5]
Measures: The efficiency of compute resources, which allows to identify areas of inefficiency.
Measuring unit: unit-less (%)
Calculation Method:

$$DCcE = \frac{\sum_{j=1}^{m} ScE_j}{m}$$

where *m* is the total number of servers from the data center.

3.1.9. Data Center Power Density (DCPD)

Proposed by: American Power Conversion[10]
Measures: Operating power density of a data center
Measuring unit: W/m^2 or W/ft^2
Calculation Method: different alternative calculation methods

$$Data\ Center\ Power\ Density_{ITracks} = \frac{Power\ Consumption\ of\ IT\ Equipment}{Area\ Ocupied\ by\ All\ IT\ Racks\ enclousers}$$

$$Data\ Center\ Power\ Density_{RacksAndClearances} = \frac{Power\ Consumption\ of\ IT\ Equipment}{Area\ Ocupied\ by\ All\ IT\ Racks\ enclousers\ and\ their\ clearances}$$

$$Data\ Center\ Power\ Density_{ITtotalSpace} = \frac{Power\ Consumption\ of\ IT\ Equipment}{Total\ Data\ Center\ Floor\ Space}$$

$$Data\ Center\ Power\ Density_{ITandFacilityTotalSpace} = \frac{Power\ Consumption\ of\ (IT\ Equipment + Facility)}{Total\ Data\ Center\ Floor\ Space}$$

[10] http://www.criticalpowerandcooling.com/white-papers/Cooling/WP-120%20Guidelines%20for%20Specification%20of%20Data%20Center%20Power%20Density.pdf

3.1.10. Data Centre Density (DCD)

Proposed by: GreenGrid
Measures: quantify the data centre space efficiency. It is calculated as a ratio between the maximum power consumed by the Data Centre and the Data Centre space area.
Measuring unit: W/m^2

$$DCD = \frac{P_{DC}\ [\mathrm{W}]}{A_{IT}\ [\mathrm{m}^2]} = \left[\frac{W}{m^2}\right]$$

Where A_{IT} is the area of each *IT* room where the IT equipment is allocated, [m^2].

3.1.11. Space, Watts, and Performance

Proposed by: Sun Microsystems[11]
Measures: Server's overall efficiency
Measuring unit: unit-less (no.)
Calculation Method:

$$SWaP = \frac{Performance}{Space * Power\ Consumption}$$

where:

- $Performance$ is based on industry standard benchmarks (e.g. SPECPower),
- $Space$ is the measurement of the size of the server in rack units,
- $Power$ is measured by determining the watts consumed by the server

3.1.12. Useful work

Measures: the quantity of useful work produced in the Data Centre according the services provided. CoolEmAll focuses on HPC environments [FLOP], Cloud [Number of service invocations] and General-purpose services [number of transactions]. Similar approaches are developed by The Green Grid to measure the useful work in Data Centres and compare it with the energy consumption as indicator of productivity.

[11] http://www.energystar.gov/ia/products/downloads/Greenhill_Pres.pdf

Measuring unit: unit-less (no.)
Calculation Method:

$$W_{DC} = \sum_{i}^{N} W_{rack,i}$$

Where *N* is the number of Racks in the Data Centre.

3.1.13. Data Centre Productivity

Measuring unit: units of work / Wh

$$Productivity_{DC} = \frac{W_{DC}\,[units\ of\ useful\ work]}{E_{DC}\,[Wh]} = \left[\frac{units\ of\ useful\ work}{Wh}\right]$$

3.1.14. Transactions per second per Watt (TPS/Watt)

Measures: Efficiency in terms of work done over power consumption
Measuring unit: Wh/units of work
Calculation Method:

$$TPS/Watt = \frac{Power\ Consumption}{Units\ of\ Work}$$

where:

- $Units\ of\ Work$ – transactions, queries, for System Under Test.
- $Power\ Consumption$ – total energy consumption in watt of the Reported Energy Configuration

3.1.15. Deployed Hardware Utilization Ratio (DH-UR)

Proposed by: Uptime Institute[12]
Measures: The power drained by the idle servers or amount of power waste

[12] http://www.dcxdc.ru/files%5C4ede4eff-13b0-49d9-b4da-b0406bfc190e.pdf

Measuring unit: unit-less (no.)
Calculation method:

$$DH - UR = \frac{Number\ of\ Servers\ Running\ Live\ Applications}{Total\ Number\ of\ Servers\ Deployed}$$

In similar manner DH-UR can be used for assessing storage systems efficiency: number of terabytes containing frequently accessed data divided by the total number of terabytes of the storage system.

3.1.16. Deployed Hardware Utilization Efficiency (DH-UE)

Proposed by: Uptime Institute[9]
Measures: The power efficiency of operating servers and storage systems
Measuring unit: unit-less (no.)
Calculation method:

$$DH - UR = \frac{Minimum\ Number\ of\ Servers\ Necesary\ to\ Handle\ Peak\ Load}{Total\ Number\ of\ Servers\ Deployed}$$

3.1.17. Site Infrastructure Power Overhead Multiplier (SI-POM)

Proposed by: Uptime Institute[9]
Measures: Measures the energy efficiency of facilities components such as transformers, UPS systems, cooling etc.
Measuring unit: unit-less (no.)
Calculation method:

$$SI - POM = \frac{Data\ Center\ Power\ Consumption\ at\ the\ Facility\ Meter}{Total\ Hardware\ Power\ Consumption\ at\ the\ Plug\ for\ all\ IT\ Equipment}$$

3.1.18. IT Hardware Power Overhead Multiplier (H-POM)

Proposed by: Uptime Institute[9]
Measures: How much of the power input to a data center is wasted in power supply conversion losses or diverted to fans rather than making it to the useful computing components.
Measuring unit: unit-less (no.)
Calculation Method:

$$H - POM = \frac{Total\ Hardware\ Load\ at\ the\ Plug\ For\ the\ Entire\ Data\ Center}{Total\ Hardware\ Compute\ Load}$$

3.1.19. Server Utilization / Hardware Utilization / Network Utilization

Proposed by: Green Grid[13]
Measures: How efficient the server CPU, the storage and the network is used.
Measuring unit: unit-less (%)
Calculation Method:

$$U_{server} = \frac{Load\ of\ the\ Server\ Processor}{Maximum\ Load\ at\ the\ Highest\ Frequency\ State}$$

$$U_{storage} = \frac{Percent\ of\ Storage\ Used}{Total\ Storage\ Capacity}$$

$$U_{network} = \frac{Percent\ of\ Network\ Bandwith\ used}{Total\ Bandwith\ Capacity}$$

3.1.20. Total harmonic distortion (THD)[14]

Measures: Characterize the power quality of electric power systems. The higher the percentage, the more distortion is present on the mains signal.
Measuring unit: unit-less (%)
Calculation Method:

$$THD = 100 * \frac{\sqrt{\sum_2^{\infty}(H_n)^2}}{H_1}$$

where:

- H_n – harmonic components of the voltage or current waveform
- H_1 – the fundamental component of the voltage or current wave

[13] http://www.poweranalytics.com/pa_articles/pdf/Power%20Analytics%20Energy%20Management%20-%20final.pdf
[14] http://www.aspowertechnologies.com/resources/pdf/Total%20Harmonic%20Distortion.pdf

3.1.21. Carbon Usage Effectiveness (CUE)

Proposed by: Green Grid[15]

Measures: Carbon emissions associated with data centers

Measuring unit: kgCO2eq / kWh

Calculation Method:

$$CUE = \frac{Total\ Carbon\ Dioxide\ Emissions\ from\ Total\ Data\ Center\ Energy}{IT\ Equipment\ Energy}$$

3.1.22. Carbon Emissions Balance[16]

Due to the operation of a data centre, it is generated a quantity of carbon dioxide that goes to the atmosphere depending on the kind energy sources used and the amount of non-renewable energy use.

$$\sum_i f_i \cdot CEF_{f,i} - \sum_i d_i \cdot CEF_{d,i}$$

3.1.23. Water Usage Effectiveness (WUE)

Proposed by: Green Grid[17]

Measures: Water usage in data centers

Measuring unit: liters/kWh

Calculation Method:

$$WUE = \frac{Annual\ water\ usage}{IT\ Equipment\ Energy}$$

3.1.24. Energy Reuse Factor (ERF)

Proposed by: Green Grid[18]

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15 http://www.thegreengrid.org/~/media/WhitePapers/Carbon%20Usage%20Effectiveness%20White%20Paper_v3.pdf?lang=en

16 http://www.coolemall.eu/documents/10157/25512/CoolEmAll+-+D5.1+Metrics+v1.4.pdf?version=1.0

17 http://www.thegreengrid.org/~/media/WhitePapers/WUE

18 http://www.thegreengrid.org/~/media/WhitePapers/ERE_WP_101510_v2.pdf?lang=en

Measures: Reuse of waste heat energy from the data center in other parts of the facility with beneficial results *Measuring unit:* unit-less (no.)

Calculation Method:

$$ERF = \frac{Resuse\ Energy}{Total\ energy}$$

ERF ranges from 0.0 to 1.0, with 0.0 meaning no energy is exported and 1.0 means all energy brought into the data center is reused outside of the data center.

The Global Taskforce in Harmonizing Global Metrics for Data Centre Energy Efficiency recommends the use of Energy Reuse Factor[19], defined as:

$$ERF = \frac{ER_{out-DC}}{E_{DC}} = [\emptyset]$$

The calculation of ERF requires the clear definition of boundaries of data centre. The Global Taskforce states that the different kind of energies (electricity, chilled water, etc) reused from data centre should be unified using the appropriate conversion factors

3.1.25. Energy Reuse Effectiveness (ERE)

Proposed by: Green Grid[18]

Measures: The energy efficiency in data centers that re-use waste energy from their own data center

Measuring unit: unit-less (no.)

Calculation Method:

$$ERE = (1 - ERF) * PUE = \frac{Cooling + Power + Lightning + IT\ Energy - Reuse}{IT\ Energy}$$

3.1.26. Carbon Emission Factor (CEF)

Proposed by: Green Grid[15]

Measures: The level of CO2 emissions for a data center site

Measuring unit: unit-less (no.)

[19] Global Metrics Harmonization Task Force, Global Taskforce Reaches Agreement on Measurement Protocols for GEC, ERF, and CUE – Continues Discussion of Additional Energy Efficiency Metrics, 2012

Calculation Method:

$$CEF = \frac{CUE}{PUE}$$

CEF can be also measured as kgCO2eq/kWh of the site, based on the government's published for the region of operation for a specific year.

3.1.27. Carbon Intensity per Unit of Data (CIUD)

Proposed by: Akamai[20]

Measures: The carbon emissions related to data center services activity

Measuring unit: kgCO2/gbs

Calculation Method:

$$CIUD = \frac{Tons\ of\ carbon\ equivalent\ gasses\ emitted}{Gigabit\ of\ traffic\ transmitted\ per\ second}$$

3.1.28. Green Power Usage Effectiveness (GPUE)

Proposed by: greenqloud[21]

Measures: Amount of CO2 to be emitted by DC use of dirty or clean energy.

Measuring unit: kgCO2/kWh

Calculation Method:

$$GPUE = \sum [\frac{EnergySource}{100} * (1 + w)] * PUE$$

Where:

- $EnergySource$ – energy source lifecycle kgCO2/kWh
- w – energy source weight (weights are taken directly from the "lifecycle CO2/kWh for electricity generation by power source" Study[22])

[20] http://www.datacenterdynamics.com/focus/archive/2013/09/akamais-data-center-carbon-fight

[21] http://greenqloud.com/greenpowerusageeffectiveness-gpue/

[22] Benjamin K. Sovacool. A Critical Evaluation of Nuclear Power and Renewable Electricity in Asia, Journal of Contemporary Asia, Vol. 40, No. 3, August 2010, p. 386.

3.1.29. PAR4

Proposed by: Power Assure[23]

Measures: Energy efficiency of data centers servers.

Measuring unit: unit-less (%)

Calculation Method:

$$Par4 = \log_2(TPS/Watt) * 100$$

The measurement is made at 100% CPU load, and the power draw is measured at the server plug

3.1.30. Global KPI of Energy Efficiency[24][25]

Measures: The Global KPI of Energy Efficiency is currently under discussion at ETSI. This KPI (Key Performance Indicator) is a combination of up to four "objective" KPIs: Energy Consumption (KPI_{EC}), Renewable Energy (KPI_{REN}), Energy Reuse (KPI_{REUSE}) and Task Efficiency (KPI_{TE}) and reflects energy impact:

- reduced energy consumption (KPI_{EC}) - the total consumption of energy by an operational infrastructure
- improved task efficiency (KPI_{TE}) - a measure of the work done for a given amount of energy consumed
- re-use of energy (KPI_{REUSE}) - transfer or conversion of energy produced by the operational infrastructure to do other work
- use of renewable energy (KPI_{REN}) - produced from dedicated generation systems using resources that are naturally replenished

Measuring unit: Wh

Calculation method:

$$KPI_{EE} = (KPI_{EC} - w_{REN} \cdot KPI_{REN} - w_{REUSE} \cdot KPI_{REUSE}) \cdot KPI_{TE}$$

where:

- w_{REN} – weighting factor for renewable energy
- w_{REUSE} – weighting factor for energy – reuse

[23] http://www.powerassure.com/pdf/collateral/451-par4_spotlight_20110617.pdf

[24] R. Bolla, "STF439 - Global KPIs for energy efficiency of deployed broadband," ETSI Workshop on Energy Efficiency, Genova, Italy, June 2012

[25] M. Gilmore, "Energy Efficiency Standards," 2012. [Online]. Available: http://www.fia-online.co.uk/pdf/Presentation/L5990a.pdf

3.1.31. Data Centre Performance per Energy (DPPE)

Measures: Developed by the Green IT Promotion Council (GIPC)[26][27] the DPPE, aims to integrate several energy efficiency parameters in one. It includes the assessment of facility efficiency using PUE, the CO_2 emissions associated to energy purchased using GEC, the efficiency features of IT equipment using ITEE and the IT equipment utilisation using ITEU.

$$DPPE = ITEU \cdot ITEE \cdot \frac{1}{PUE} \cdot \frac{1}{1 - GEC}$$

Measuring unit: unit-less (no.)

A larger DPPE indicates higher energy efficiency with a maximum of 1.0.

The ITEU is named IT Equipment Utilisation and is defined as the actual energy consumption divided by the total rated energy (rated power by time of measurement), of IT equipment. The corresponding formula is:

$$ITEU = \frac{E_{IT}}{E_{IT,rated}}$$

This metric has relation with DCU, although ITEU is referred to energy consumption and DCU to power capacity.

The ITEE is named IT Equipment Energy Efficiency. This metrics consist of the quotient between the total rated capacity of work of IT equipment and the total rated power of IT equipment. It is expressed in formula below:

$$ITEE = \frac{W_{DC,rated}[units\ useful\ work]}{P_{DC,rated}[W]}$$

3.1.32. IT- power usage effectiveness (ITUE)[28]

Measures: Total energy consumption into the compute components

Measuring unit: unit-less (no.)

Calculation Method:

$$ITUE = \frac{Total\ energy\ into\ the\ \ IT\ equipment}{Total\ energy\ into\ the\ compute\ components}$$

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[26] Green IT Promotion Council, “Enhancing the Energy Efficiency and Use of Green Energy in Data Centers.,” September 2012.

[27] Green IT Promotion Council, “New Data Center Energy Efficiency Evaluation Index. DPPE (Datacenter Performance per Energy). Measurement Guidelines (Ver 2.05),” March 2012

[28] REF: Michael K Patterson et all, “TUE, a new energy-efficiency metric applied at ORNL's Jaguar”, paper presented to supercomputing 2013.

Where "IT" represents only the compute components (CPU, memory, fabric) but not cooling, power supplies or voltage regulators.

3.1.33. Total power usage effectiveness (TUE)

Measures: TUE is the total energy into the data center divided by the total energy to the computational components inside the IT equipment

Measuring unit: unit-less (no.)

Calculation Method:

$$TUE = ITUE \times PUE$$

ITUE and TUE should also be extended to cover the full spectrum of the IT equipment in the data center.

3.1.34. Data Centre Fixed to Variable Energy Ratio (DC FVER)

Proposed by: the BCS (British Computer Society)[29]

Measures: The Data Centre Fixed to Variable Energy Ratio metric (DC FVER) measures for the first time what proportion of data centre energy consumption is variable, i.e. related to the useful work delivered, versus what proportion is fixed allowing operators to understand how much of their energy cost is related to the work delivered and how much is a fixed burden to be eliminated.

Measuring unit: unit-less (no.)

Calculation Method:

$$FVER = 1 + \frac{Fixed\ Energy\ (\boldsymbol{KWh})}{Variable\ Energy\ (\boldsymbol{KWh})}$$

3.1.35. Partial Power Usage Effectiveness (pPUE)

Proposed by: **Green Grid**[30]

Measures: Often PUE's are presented that do not take into account all of the infrastructure components in order to highlight one particular portion (boundary) of a data center. The partial PUE or pPUE is Total Energy within a boundary divided by the IT Equipment Energy within that boundary.

Measuring unit: unit-less (no.)

[29] http://dcsg.bcs.org/sites/default/files/protected/DC%20FVER%20Metric%20v1.0.pdf

[30] http://www.thegreengrid.org/~/media/TechForumPresentations2011/Data_Center_Efficiency_Metrics_2011.pdf

Calculation Method:

$$pPUE = \frac{Total\ Energy\ within\ boundary\ (\boldsymbol{KWh})}{IT\ Equipement\ Energy\ within\ boundary\ (\boldsymbol{KWh})}$$

3.1.36. IT Equipment Energy Utilization (ITEU)

Proposed by: **Green IT Promotion Council**[31]

Measures: ITEU (IT Equipment Energy Utilization) allows measuring the efficient operation of IT equipment. It is an approach to improve utilization ratio through consolidation and virtualization and by reducing the number of equipment in operation.

Measuring unit: unit-less (no.)

Calculation Method:

$$ITEU = \frac{Total\ energy\ consumption\ of\ IT\ equipment\ (actual\ in\ \boldsymbol{KWh})}{Total\ rated\ energy\ consumption\ of\ IT\ equipment\ (rated\ in\ \boldsymbol{KWh})}$$

3.1.37. IT Equipment Energy Efficiency (ITEE)

Proposed by: **Green IT Promotion Council**[32]

Measures: ITEE (IT Equipment Energy Efficiency) is an approach to introduce IT equipment with higher energy saving performance.

Measuring unit: unit-less (no.)

Calculation Method:

$$ITEE = \frac{Total\ rated\ capacity\ of\ IT\ equipment\ (rated\ in\ \boldsymbol{KWh})}{Total\ rated\ power\ of\ IT\ equipment\ (rated\ in\ \boldsymbol{KWh})}$$

3.1.38. Energy Consumption KPI (KPI_{EC})

Proposed by: ETSI[33]

[31] http://home.jeita.or.jp/greenit-pc/e/topics/release/100316_e.html
[32] http://home.jeita.or.jp/greenit-pc/e/topics/release/100316_e.html
[33] http://www.etsi.org/deliver/etsi_gs/OEU/001_099/001/01.01.01_60/gs_oeu001v010101p.pdf

Measures: KPI_{EC} is an operational Key Performance Indicators corresponding to the energy consumption. The energy consumption to be included in KPI_{EC} comprises that of buildings containing IT rooms, technical infrastructure and spaces required for proper operation of the data centre (including, but not limited to: security, guards, maintenance, management of IT rooms).

Measuring unit: kWh

Energy consumption excluded from this KPI includes buildings containing offices for on-site employees.

Calculation Method:

$$KPI_{EC} = EC_{SP} + EC_{FEN} + EC_{REN} + (EC_{TH} \times K_{TH})$$

Where:

- EC_{SP} = consumption of utility electricity (KWh)
- EC_{FEN} = total of electricity consumptions based on fossil energy (KWh)
- EC_{REN} = total of energy consumption from renewable sources (KWh)
- EC_{TH} = energy consumption for externally-provided thermal energy (either hot or cold) (KWh)
- K_{TH} = conversion ratio from electricity to thermal energy (No unit)

3.1.39. Task Efficiency KPI (KPI_{TE})

Proposed by: ETSI[34]

Measures: KPI_{TE} is an operational Key Performance Indicators corresponding to the task efficiency. KPI_{TE} is the ratio of the electricity consumption of all the components, whatever they are, to that of the components that manage data, for calculation storage or transport purposes.

Measuring unit: unit-less (no.)

Calculation Method:

$$KPI_{TE} = \frac{EC_{DC}}{EC_{HE}}$$

where:

- EC_{DC} = *Total of energy consumptions by a data centre over a year (**KWh)**.*
- EC_{HE} = *Total of energy consumptions by equipment processing data, for purposes of calculating, storing or transporting, over a year (**KWh)**.*

[34] http://www.etsi.org/deliver/etsi_gs/OEU/001_099/001/01.01.01_60/gs_oeu001v010101p.pdf

3.1.40. Energy Reuse KPI (KPI_{REUSE})

Proposed by: ETSI[35]

Measures: KPI_{REUSE} is an operational Key Performance Indicators corresponding to the energy reuse. KPI_{REUSE} is the ratio of reused energy for external uses to total data centre energy. Thermal energy can be reused in different forms, liquid or gas (air).

Measuring unit: unit-less (no.)

Calculation Method:

$$KPI_{REUSE} = \frac{EC_{REUSE}}{EC_{DC}}$$

Where:

- *EC_{DC} = Total of energy consumptions by a data centre over a year (KWh).*
- *EC_{REUSE} =Measurement of reused energy (KWh).*

3.1.41. Renewable Energy KPI (KPI_{REN})

Proposed by: ETSI[36]

Measures: KPI_{REN} is an operational Key Performance Indicators corresponding to the use of renewable energy. KPI_{REN} is the ratio of local renewable energy over the total data centre energy consumption. It is a dimensionless number.

Measuring unit: unit-less (no.)

Calculation Method:

$$KPI_{REN} = \frac{EC_{REN}}{EC_{DC}}$$

Where:

- *EC_{REN} =Measurement of renewable energy (KWh).*
- *EC_{DC} = Total of energy consumptions by a data centre over a year (KWh).*

[35] http://www.etsi.org/deliver/etsi_gs/OEU/001_099/001/01.01.01_60/gs_oeu001v010101p.pdf
[36] http://www.etsi.org/deliver/etsi_gs/OEU/001_099/001/01.01.01_60/gs_oeu001v010101p.pdf

3.1.42. Global Synthetic KPI (KPI_{GP})

Proposed by: ETSI[37]

Measures: KPI_{GP} is a Global Synthetic KPI (KPI_{GP}) that allows benchmarking the energy efficiency of data centres depending on their gauge. The four previous KPIs are used to define this KPI_{GP}. KPI_{GP} applies to all data centres of all sizes and includes IT rooms located in buildings

KPI_{GP} is composed of two values, DC_G and DC_P, where:

- DC_G defines the energy consumption gauge of the DC;
- DC_P defines the performance of the DC for the relevant gauge.

The next table presents the DC_G gauges :

DC_G	KPI_{EC}
S	$KPI_{EC} \leq 1$ GWh
M	1 GWh < $KPI_{EC} \leq 4$ GWh
L	4 GWh < $KPI_{EC} \leq 20$ GWh
XL	$KPI_{EC} > 20$ GWh

Calculation Method for DC_P:

$$DC_P = KPI_{TE} \times (1 - W_{REUSE} \times KPI_{REUSE}) \times (1 - W_{REN} \times KPI_{REN})$$

Where:

- W_{REUSE} = Mitigation factor for KPI_{REUSE} (the value may vary depending on the gauge within the range 0 to 1, the default value is 0,5).
- W_{REN} = Mitigation factor for KPI_{REN} (the value may vary depending on the gauge within the range 0 to 1, the default value is 0,5).

3.1.43. Cooling Capacity Factor (CCF)

Proposed by: Upsite[38]

[37] http://www.etsi.org/deliver/etsi_gs/OEU/001_099/001/01.01.01_60/gs_oeu001v010101p.pdf

Measures: The average computer room today has cooling capacity that is nearly four times the IT heat load. The Cooling Capacity Factor (CCF) is a simple and practical metric allowing to determine cooling infrastructure utilization and potential gains to be realized by airflow management.

Measuring unit: unit-less (no.)

Calculation Method:

$$Cooling\ Capactiy\ Factor\ (CCF) = \frac{Total\ Running\ Cooling\ Capacity\ (kW)}{UPS\ Output\ (kW) \times 1.1}$$

where:

- $Total\ Running\ Cooling\ Capacity\ (kW\ or\ refrigeration\ tons)$ = The total running cooling capacity is the sum of the running cooling units' rated capacities. If all cooling units are running, then this will be the same value as the total installed rated cooling capacity. If there are 10 cooling units installed with a rated capacity of 30 tons each and seven are running, then the total running cooling capacity is 739 kW (7 x 30 tons = 210 tons, 210 tons x 3.52 = 739 kW). To convert tons to kW, multiply tons by the constant 3.52.
- $UPS\ Output\ (kW)$ = The IT critical load in the room is equal to the UPS output(s) for the room. Ensure that the UPS output used is only for the room being calculated. If the UPS feeds other rooms, then those loads must be subtracted from the total UPS output. To account for typical room load not reflected in the UPS output, add 10% for lights, people, and building envelope.
- $Cooling\ Capactiy\ Factor\ (CCF)$ determine the action to do on the airflow management :
    - For rooms with a CCF of 1.0 to 1.1, there is little to no redundant cooling capacity.
    - For rooms with a CCF of 1.2 to 1.5, there is moderate opportunity to realize savings from turning off cooling units.
    - A CCF of 1.5 to 3.0 is most common. These rooms have substantial opportunity to reduce operating cost, improve the IT environment, and increase the IT load that can be effectively cooled. Rooms in this range often have significant stranded cooling capacity that can be freed up by improving airflow management
    - Rooms with a CCF greater than 3.0 have great potential for improvement since the total rated cooling capacity of running units is at least three times 110% of the IT load.

3.1.44. Data Center Maturity Model (DCMM)

Proposed by: Green Grid[39]

Measures: The Green Grid has developed the Data Center Maturity Model (DCMM) and supporting white paper to outline capability descriptors by area such that users can benchmark their current performance, determine their levels of maturity, and identify the ongoing steps and innovations necessary to achieve greater energy efficiency and

[38] http://www.upsite.com/cooling-capacity-factor-white-paper
[39] http://www.thegreengrid.org/en/Global/Content/white-papers/DataCenterMaturityModel

sustainability, both today and into the future. The maturity model touches upon every aspect of the data center including power, cooling, compute, storage and network. The levels of the model outline current best practices and a 5-year roadmap for the industry.

Calculation Method: Not applicable

3.1.45. Code of Conduct

Proposed by: European Commission[40]

Measures: This Code of Conduct has been created in response to increasing energy consumption in data centres and the need to reduce the related environmental, economic and energy supply security impacts. The aim is to inform and stimulate data centre operators and owners to reduce energy consumption in a cost-effective manner without hampering the mission critical function of data centres. The Code of Conduct aims to achieve this by improving understanding of energy demand within the data centre, raising awareness, and recommending energy efficient best practice and targets.

Calculation Method: Not applicable

3.1.46. Physical Server Reduction Ratio (PSRR)

Measures: PSRR is the ratio of the historical installed server base to installed server base after virtualization. For example, a PSRR of 3:1 indicates a server base reduced by one-third after virtualization. Virtualization is an innovative technology that consolidates and optimizes servers, storage, and network devices in real time and thereby reduces energy use.

Measuring unit: unit-less (no.)

$$PSRR = \frac{HistoricalInstalledServerBase}{PostVirtualizationInstalledServerBase}$$

3.1.47. Data Centre Measurement, Calculation and Evaluation Methodology (DOLFIN Project)

The general approach to be used for the evaluation of DOLFIN can be thought of having the following steps/phases:

- Identify a set of well documented and clear KPIs or energy metrics for Data Centres.

[40] http://iet.jrc.ec.europa.eu/energyefficiency/ict-codes-conduct/data-centres-energy-efficiency

- Define the way that these KPIs will be measured and, eventually, calculated for each one of the pilot Data Centres of DOLFIN.
- Make and initial calculation of the KPIs, without having applied any of the DOLFIN's mechanisms. In this manner we will establish a base-line for comparison.
- As the DOLFIN system becomes available, even partially, we will recalculate the KPIs. In general, recalculation of the KPIs will be done after a major change in DOLFIN system or after any significant tune-up.
- Compare the evolving values of the KPIs and establish the relationships between them and the base-line of the KPIs.

Data Centres are considered as industrial facilities housing a collection of IT equipment (servers, storage and network devices) in a dedicated space. We refer to the IT portion of a Data Centre collectively as the "IT infrastructure." A Data Centre's IT infrastructure is served by the facility's power, cooling, and lighting systems, which we refer to collectively as the "site infrastructure." Data Centre energy performance is typically measured separately for IT and site infrastructure.

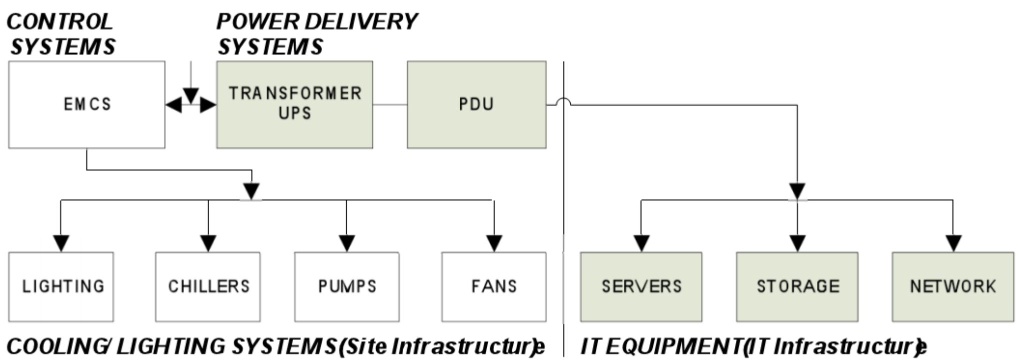

Figure 2. DC Power consumption and distribution architecture

The metric to assess IT infrastructure energy use and overall Data Centre utilization is a standard measurement of either billion operations per second per kW, based on load profiling from a middleware platform. Billion operations per second is also sometimes referred to as billions of processes per second (BOPS) or floating point operations per second (FLOPS). Mixed-use Data Centres typically use the metrics kW/rack and W/m^2, which vary from 2.5kW/rack to more than 20kW/rack. These estimates are based on standard four-post racks that are 42 units (roughly two meters high). The Data Centre industries (e.g., the Green Grid) are working on defining appropriate metrics to understand true IT utilization (computing horsepower) relative to net power consumption.

3.1.48. Grid Efficiency (All4Green Metric)

The difference between the energy generated from various sources and the energy consumed by customers (be it the data centre federation or others) represents the efficiency of energy transportation in the grid. Of course this efficiency should be close to 1.

Measuring unit: unit-less (no.)

$$GridEfficiency\ (\Delta t) = \frac{TotalEnergyConsumed(DCF, Others, \Delta t)}{TotalEnergyProduced(EP, \Delta t)}$$

3.1.49. Energy Consumed by Service (All4Green Metric)

$$EnergyConsumedByService(Services) = \sum_{x} UR_{\frac{s}{x}} * kWh_x$$

where

- $UR_{\frac{s}{x}}$ - Utilization Rate of service s in Server x
- kWh_x - Energy consumed by server x (during the run-time of service s)

Servers should be all (computation, storage, network, security) – if possible.

3.1.50. Energy saving vs. Quality of service (All4Green Metric)

The amount of energy that can be saved by a single flexibility in comparison to the loss of service quality. Flexibility is a possibility/mechanism to save energy in a DC (example switching off the cooling system for a short period of time).

$$FLEX\ = \frac{\boldsymbol{\Delta}Power\%}{1 + \ \boldsymbol{\Delta}Quality\ of\ Service\%}$$

In order not to divide by 0, the denominator of the flexibility is defined by ($1 + \ \boldsymbol{\Delta}Quality\ of\ Service\%$). The closer to $\boldsymbol{\Delta}Power\%$ FLEX is the better. In rare cases power may be reduced even though the QoS is positive (e.g. because of efficiency gains); in this case FLEX is even negative.

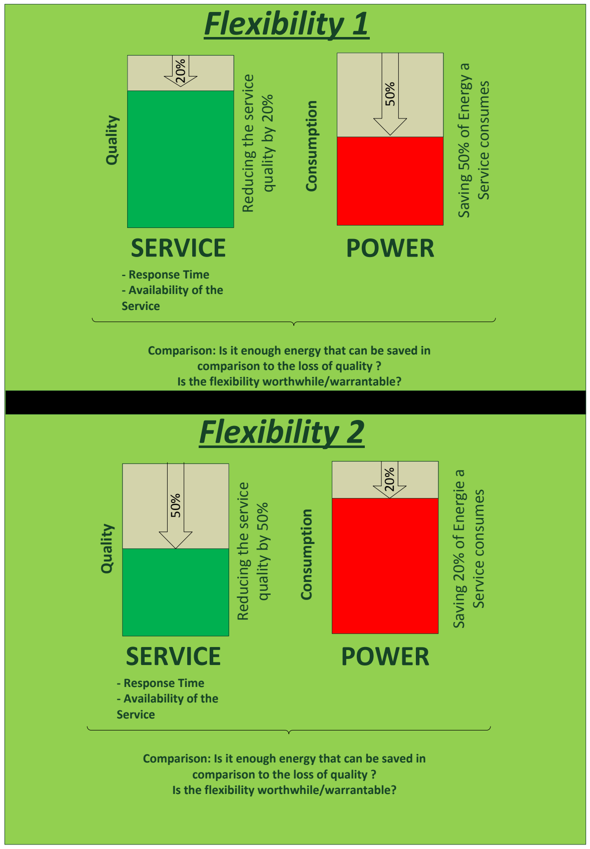

Figure 3. Flexibilities and their impact on the service quality and the power consumption

Figure 3 above shows two flexibilities and their impact on the service quality and the power consumption. During the definition of flexibility there is a need to figure out if the flexibility is worthwhile or not. So there must be an analysis how the quality of a service will be impacted in comparison to the reduction of power consumption when such flexibility will be executed. For flexibility number one in the picture above the service quality will go down to 80 percent and the power consumption will go down to 50 percent. The power saving value is higher than the loss in service quality so the flexibility is more warrantable than flexibility number two. In flexibility number two the service quality goes down to 50 percent and the power consumption goes down to 80 percent.

3.1.51. Maximum and Minimum Site Energy Saving (All4Green Metric)

$MaximumSiteEnergySaving\ (DC,\ \Delta t)$: Maximum amount of energy that can be saved compared to overall power consumption of data centre during a time range of 30 minutes.

$MinimumSiteEnergySaving(DC, \Delta t)$: Minimum amount of energy that can be saved compared to overall power consumption of data centre during a time range of 30 minutes.

3.1.52. Green Energy Coefficient (GEC)

Proposed by: Green IT Promotion Council[41]

Measures: GEC is a value of consumption of green energy produced by photovoltaic or wind generation on the premises of the data center divided by total energy consumption at the data center.

Measuring unit: unit-less (no.)

Calculation Method:

$$GEC = \frac{\text{The amount of green energy generated and used on the premises of the data center (KWh)}}{\text{Total energy consumptionat the data center (KWh)}}$$

*Green energy: energy generated by using such natural energy sources as solar light and wind

3.1.53. MHz/Watt

3.1.54. Bandwidth/Watt

3.1.55. StorageCapacity/Watt

3.1.56. IOPS/Watt

[41] http://home.jeita.or.jp/greenit-pc/e/topics/release/100316_e.html

3.2. Cooling - energy / power consumption (loads)

3.2.1. Coefficient of Performance of the Ensemble (COP)

Proposed by: HP[42]
Measures: The ratio of total heat load to the power consumed by the cooling infrastructure
Measuring unit: unit-less (no.)
Calculation Method:

$$COP = COP_{coolingsystem} + COP_{airconditioningsystem(humidifierandfans)}$$

or

$$COP = \frac{Total\ Heat\ Disipation}{(Flow\ Work + Thermodynamic\ Work)\ of Coling\ System} = \frac{Heat\ Extracted\ by\ Air\ Conditioners}{Net\ Work\ Input}$$

where:

$$Heat\ Extracted\ by\ Air\ Conditioners = \sum_{l}(Q_{cr} + Q_{b-cr})$$

$$Net\ Work\ Input = \sum_{l}(W_b + W_{humid-dehumid})$$

where:

- Q_{cr} - cooling load (heat generated by the data center + external conditions)
- Q_{b-cr}- heat from the blower that must also be extracted in addition to the heat generated in the data center
- W_b - blower power consumption
- $W_{humid-dehumid}$ - power consumption required to periodically humidify or dehumidify the air in the data center
- l - l^{th} CRAC unit.

3.2.2. Energy Efficient Ratio (EER)

Measures: the cooling capacity divided by the power usage of the cooling system[43]. This indicator is provided by cooling machines manufacturers under standard conditions. However optimization of cooling facilities in data centres often

42 http://proceedings.asmedigitalcollection.asme.org/proceeding.aspx?articleid=1605569
43 ASHRAE, ASHRAE Handbook 2012, HVAC Systems and Equipment, 2012

makes them work far away of the standard conditions, therefore the periodical observation of the obtained EER gives a continuous assessment of the energy efficiency of the cooling system.
Measuring unit: unit-less (no.)
Calculation Method:

$$EER = \frac{Q_{cooling}\ [W_{th}]}{P_{cooling}\ [W_{el}]} = [\emptyset]$$

where,

- $Q_{cooling}$ is the heat removed by the cooling system, [W_{th}].
- $P_{cooling}$ is the electrical power used by the cooling system, [W_{el}].

3.2.3. Seasonal Energy Efficient Ratio (SEER)

Measures: the cooling energy output during the typical season when cooling is required and divided by the energy consumption of the cooling system during the same period. This indicator is also given by manufacturers under a season standard conditions that are defined with the aim of being able to compare different equipment.
Measuring unit: unit-less (no.)
Calculation Method:

$$SEER = \frac{Q_{cooling,year}\ [Wh_{th}]}{E_{cooling,year}\ [Wh_{el}]} = [\emptyset]$$

$$Q_{cooling,year} = \int_0^Y q_{cooling}(t) \cdot dt = [Wh_{th}]$$

where,

- $E_{cooling,year}$ is the energy consumed by the cooling system of the Data centre during a whole year, [Wh_{el}].
- Y is one year.
- $q_{cooling}$ is the instant heat removed by the cooling system of the Data centre, [Wh_{th}].

3.2.4. Imbalance of Racks Temperature

Proposed by: Collemall project[44] [45]

[44] http://www.coolemall.eu/documents/10157/25512/CoolEmAll+-+D5.1+Metrics+v1.4.pdf?version=1.0
[45] Energy- and Heat-aware Metrics for Data Centers
Laura Sisó, Jaume Salom, Ariel Oleksiak and Thomas Zilio, , EuroEcoDC Workshop, Karlsruhe, Germany, Oct, 2013

Measures: can help on the identification of hotspots and air recirculation problems.
Measuring unit: unit-less (%)
Calculation Method:

$$Im_{DC,temp} = \frac{T_{rack,max} - T_{rack,min}}{T_{rack,avg}} * 100 = [\%] \; ; \; T_{rack,avg} = \frac{1}{N}\sum_{i}^{N} T_{rack,i}$$

where,

- $T_{rack,i}$ is the temperature of each Rack in the Data centre.
- N is the quantity of Racks in the Data centre.
- $T_{rack,max}$ is the maximum temperature reached by the Racks during a given period of time.
- $T_{rack,min}$ is the minimum temperature of the Racks during a given period of time.

3.2.5. HVAC Effectiveness

Proposed by: Lawrence Berkeley National Laboratory[11]
Measures: The overall efficiency potential for HVAC systems. A higher value of this metric means higher potential to reduce HVAC energy use.
Measuring unit: unit-less (no.)
Calculation Method:

$$HVAC\ Efectiveness = \frac{IT}{HVAC + (Fuel + Steam + Chilled\ Watter) * \ 293}$$

where:

- IT: Annual IT Electrical Energy Use
- HVAC: Annual HVAC Electrical Energy Use
- Fuel: Annual Fuel Energy Use
- Steam: Annual District Steam Energy Use
- Chilled Water: Annual District Chilled Water Energy Use

3.2.6. Rack Cooling Index (RCI)

Proposed by: American Society of Heating, Refrigerating and Air-Conditioning Engineers[46]
Measures: How effectively equipment racks are cooled and maintained within industry thermal guidelines and

[46] http://ancis.us/images/RCI.pdf

standards. There are two RCI metrics for measuring the equipment room health at the high (HI) end and at the low (LO) end of the temperature range.

Measuring unit: unit-less (%)

Calculation Method:

$$RCI_{HI} = \left[1 - \frac{\sum(T_x - T_{maxRec})_{T_x > T_{maxRec}}}{(T_{maxAll} - T_{maxRec}) * n}\right] * 100$$

where:

- T_x - mean temperature at intake x [°F or °C]
- n - total number of intakes
- T_{maxRec} - max recommended temperature per some guideline or standard [°F or °C]
- T_{maxAll} - max allowable temperature per some guideline or standard [°F or °C]

$$RCI_{LO} = \left[1 - \frac{\sum(T_{minRec} - T_x)_{T_x < T_{minRec}}}{(T_{minRec} - T_{minAll}) * n}\right] * 100$$

where:

- T_x - mean temperature at intake x [°F or °C]
- n - total number of intakes
- T_{minRec} - min recommended temperature per some guideline or standard [°F or °C]
- T_{minAll} - min allowable temperature per some guideline or standard [°F or °C]

3.2.7. Data Center Cooling System Efficiency (CSE)

Proposed by: Lawrence Berkeley National Laboratory[47]

Measures: The overall efficiency of the cooling system (including chillers, pumps, and cooling towers) in terms of energy input per unit of cooling output.

Measuring unit: unit-less (no.)

Calculation Method:

$$CSE = \frac{Average\ cooling\ system\ power\ usage}{Average\ cooling\ load}$$

[47] http://hightech.lbl.gov/benchmarking-guides/

3.2.8. Air Economizer Utilization (AEU)

Proposed by: Lawrence Berkeley National Laboratory[13]

Measures: The extent to which air-side economizer system is being used in one year of continuous load.

Measuring unit: unit-less (no.)

Calculation Method:

$$AEU = \frac{Air\ economizer\ hours}{24 * 365}$$

3.2.9. Water Economizer Utilization (WEU)

Proposed by: Lawrence Berkeley National Laboratory[13]

Measures: The extent to which the water economizer system is being used in one year of continuous load. *Measuring unit:* unit-less (no.)

Calculation Method:

$$WEU = \frac{Water\ economizer\ hours}{24 * 365}$$

3.2.10. Airflow Efficiency (AE)

Proposed by: Lawrence Berkeley National Laboratory[13]

Measures: Overall airflow efficiency in terms of the total fan power required per unit of airflow. This metric provides an overall measure of how efficiently air is moved through the data center.

Measuring unit: unit-less (%)

Calculation Method:

$$AE = \frac{Total\ fan\ power}{Total\ fan\ airflow} * 1000$$

3.2.11. Air management flow indicators[48] [49]

Measures: In data centres, the cooling systems performance depends in a high way from air management performance. Then the logical way is by quantifying the factors of the effectiveness decrease of data centre air cooling. These factors and the air mass transfers are shown in figure below.
Measuring unit: unit-less (no.)

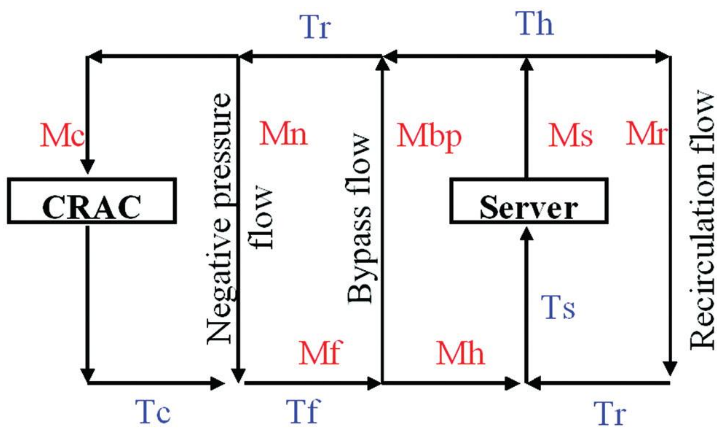

Figure 1. Data centre air mass flows

Temperatures definition is:

- T_r is the return air temperature to CRAC
- T_c is the discharge air temperature from CRAC.
- T_f is the air temperature under the floor after room air is drawn in, very close to T_c.
- T_s is the server inlet air temperature.
- T_h is the server outlet air temperature.

The air management inefficiencies come from three different phenomena: negative pressure ratios (NP), bypass air flow (BP) and recirculation air flow (R) largely affect the heat removal efficiency of ventilation. In the mentioned paper is defined some metrics to assess on the evaluation of these phenomena.

Flow performance: Defines directly how much cooled air is really being used by the IT equipment.

$$\eta_{flow} = \frac{m_f}{m_c} = \frac{T_r - T_c}{T_h - T_c} = [\emptyset]$$

Thermal performance: Defines directly how much of the air used by IT equipment really comes from CRAC/CRAH.

[48] Tozer, Kurkjian and Salim, “Air Management Metrics in Data Centers,” 2009.
[49] R. Tozer and S. Flucker, “Data Center Cooling Performance Metrics,” 2011

$$\eta_{thermal} = \frac{m_f}{m_s} = \frac{T_h - T_s}{T_h - T_c} = [\emptyset]$$

3.2.12. Cooling System Sizing (CSS)

Proposed by: Lawrence Berkeley National Laboratory[13]

Measures: The installed cooling capacity efficiency.

Measuring unit: unit-less (no.)

Calculation Method:

$$CSS = \frac{Installed\ chiller\ capacity}{Peak\ chiller\ load}$$

3.2.16. Return Temperature Index (RTI)

Proposed by: ASHRAE[50]

Measures: The Return Temperature Index (RTI) is a measure of the performance of the air-management system and how well it controls by-pass and recirculation air.

Measuring unit: unit-less (%)

Calculation Method1:

$$RTI = \frac{\Delta T_{AHU}}{\Delta T_{Euip}} \times 100\% = \frac{V_{AHU}}{V_{Euip}} \times 100\%$$

where:

- RTI = *Return Temperature index.*
- ΔT_{AHU} = *Temperature drop across the air-handler units (airflow weighted average)in °C or°F.*
- ΔT_{Euip} = *Temperature rise across the IT-equipment (airflow weighted average) in °C or°F.*
- V_{AHU} = *Total airflow rate through the air-handler units in m3/h.*
- V_{Euip} = *Total airflow rate through the IT-equipment in m3/h.*

Calculation Method2:

$$RTI = \left[\left(T_{Return} - T_{supply}\right)/\Delta T_{equip}\right] * 100\ [\%]$$

where:

[50] http://www.ancis.us/images/OR-10-003_Final_Web.pdf

- T_{Return}: return air temperature (weighted average)
- T_{supply}: supply air temperature (weighted average)
- ΔT_{equip}: temperature rise across the electronic equipment (weighted average)

3.2.17. Return Heat Index (RHI)

Proposed by: Sharma, Bash and Patel[57]

Measures: The Return Heat Index (RHI) is the ratio of the total extraction by the cooling units to the total enthalpy rise at the rack exhaust and describes the degree of air mixing before the return air reaches the cooling unit (equivalent to RTI).
Measuring unit: unit-less (no.)

Calculation Method:

$$RHI = \left(\frac{Q}{Q+\delta Q}\right) = \frac{\sum_k M_k C_p\left((T_{in}^c)_k - T_{ref}\right)}{\sum_j \sum_i m_{i,j}^r C_p\left((T_{out}^r)_{i,j} - T_{ref}\right)}$$

$$RHI + SHI = 1$$

where:

- RHI = *Return heat index.*
- M = *Mass flow rate of air through a CRAC unit.*
- C_p = *Specific heat of air at constant pressure.*
- T_{in}^c = *Temperature of rack inlet air.*
- T_{ref} = *Temperature of cooling supply air.*
- m^r = *Mass flow rate of air through a rack.*
- T_{out}^r = *Temperature of rack outlet air.*

3.2.18. Supply Heat Index (SHI)

Proposed by: Sharma, Bash and Patel[57]

Measures: The Supply Heat Index (SHI) is the ratio of the enthalpy rise due to infiltration in the cold aisle to total enthalpy rise at rack exhaust and describes the infiltration of heat into cold aisles.

Calculation Method:

$$SHI = \left(\frac{\delta Q}{Q + \delta Q}\right) = \frac{\sum_j \sum_i \left((T_{in}^r)_{i,j} - T_{ref}\right)}{\sum_j \sum_i \left((T_{out}^r)_{i,j} - T_{ref}\right)}$$

where:

- SHI = *Supply heat index.*
- T_{in}^r = *Temperature of rack inlet air.*
- T_{ref} = *Temperature of cooling supply air.*
- T_{out}^r = *Temperature of rack outlet air.*

3.2.19. DC Recovery Phase (All4Green Metric)

$\Delta E_{CoolingVsNormal}$ - How much more energy does it consume to cool the data centre to the minimum possible temperature in comparison to the power consumption of the normal temperature level in the DC (=red area in the graph below).

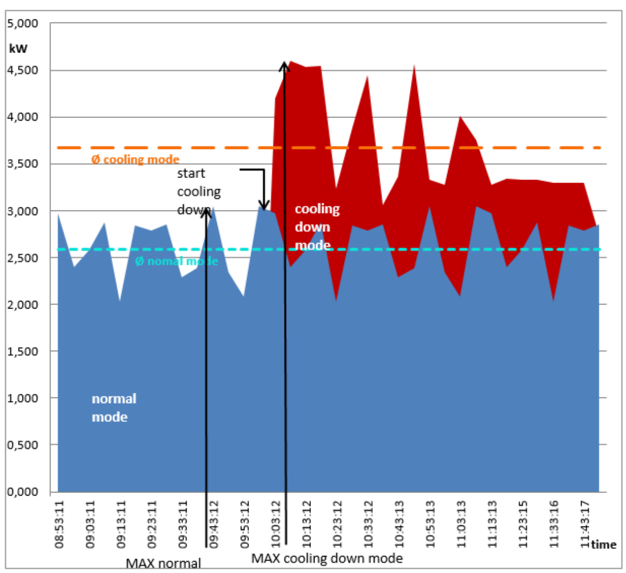

Figure 4. Temperature in the data center

$\Delta MAXE_{CoolingVsNormal}$ - What is the difference between the highest consumption value during cooling mode and the highest consumption value during normal mode. See the two arrows in the picture below, the left arrow show the highest consumption during normal mode (about 3kW) and the right arrow shows the highest consumption during cooling mode (about 4,6 kW)

$\Delta AverageE_{CoolingVsNormal}$ - What is the difference between the averages of power consumption in cooling mode (orange line in the picture) and the average in power consumption in normal mode (blue line) for a specific time.

3.2.20. Relative Humidity Difference (RHD)

Proposed by: Lawrence Berkeley National Laboratory[51]
Measures: The difference of the return and supply air relative humidity in the data center. Small relative humidity difference range suggests opportunities to reduce energy use.
Measuring unit: unit-less (%)
Calculation Method:

$$RHD = RHumidity - SHumidity$$

where:

- $SHumidity$ is the supply air relative humidity
- $RHumidity$ is the return air relative humidity

3.2.21. BTU/h

3.2.22. Data Center Temperature

3.2.23. Metrics already defined in previous sections

CADE
PUE
DCIE
CPE
DCeP
SI-POM
H-POM
THD
ERF

[51] Mathew P, Ganguly S, Greenberg S, Sartor D (2009) Self-benchmarking guide for data centers: metrics, benchmarks, actions. Technical report, Lawrence Berkeley National Laboratory, Berkeley, California, July 2009

ERE
CEF
GPUE
Global KPI of Energy Efficiency
DPPE
TUE
pPUE
KPI_{EC}
KPI_{TE}
KPI_{REUSE}
KPI_{REN}
KPI_{GP}
CCF
DCMM
Code of Conduct
PSRR
Data Centre Measurement, Calculation and Evaluation Methodology (DOLFIN)
Grid Efficiency (All4Green Metric)
Maximum and Minimum Site Energy Saving (All4Green Metric)
GEC

3.3. UPS - energy / power consumption (loads)

3.3.1. UPS Load Factor

Proposed by: Lawrence Berkeley National Laboratory[13]

Measures: UPS system over-sizing and redundancy factor

Measuring unit: unit-less (no.)

Calculation Method:

$$UPS\ Load\ Factor = \frac{UPS\ average\ load}{UPS\ load\ capacity}$$

where:

- $UPS\ average\ load$ – the average load of an UPS in a data center
- $UPS\ load\ capacity$ – the load of an UPS from technical datasheets

3.3.2. UPS System Efficiency

Proposed by: Lawrence Berkeley National Laboratory[13]

Measures: UPS efficiency

Measuring unit: unit-less (%)

Calculation Method:

$$UPS\ system\ Efficiency = \frac{UPS\ output\ power}{UPS\ input\ power} * 100$$

where:

- $UPS\ system\ Efficiency$ in %

Standard	Good	Better
85%	90%	➢ 95%

- $UPS\ input\ power$ – the power required by a UPS in *kw*
- $UPS\ output\ power$ – the power generated by a UPS in *kw*

3.3.3. UPS Usage[52]

Measures: The data centres used to have more than one UPS to obtain the desired reliability of the power infrastructure. Therefore the redundant components must not be taken into account to measure the UPS Usage. Nevertheless some data centres have many UPS just to cover the design demand and from different manufactures and capacities. The UPS Usage must be calculated by the weighted average.

Calculation method:

[52] http://www.coolemall.eu/documents/10157/25512/CoolEmAll+-+D5.1+Metrics+v1.4.pdf?version=1.0

$$UPS\ Usage_{DC} = \sum_{i}^{N} UPS\ Usage_i \cdot w_i$$

$$w_i = \frac{S_i}{C_{UPS}}\ ;\ C_{UPS} = \sum_{i}^{N} c_{UPS,i}$$

where,

- *UPS Usage*$_i$ is the utilisation ratio of each UPS.
- S_i is the apparent power drawn by the UPS measured at its input, [VA].
- $c_{UPS,i}$ is the rated apparent power of the UPS according to manufacturer specifications, [VA].

3.3.4. Metrics already defined in previous sections

CADE
PUE
DCIE
CPE
DCeP
SI-POM
H-POM
THD
ERF
ERE
CEF
GPUE
Global KPI of Energy Efficiency
DPPE
TUE
pPUE
KPI_{EC}
KPI_{TE}
KPI_{REUSE}

KPI_{REN}
KPI_{GP}
CCF
DCMM
Code of Conduct
PSRR
Data Centre Measurement, Calculation and Evaluation Methodology (DOLFIN)
Grid Efficiency (All4Green Metric)
GEC

3.4. Transformer - energy / power consumption (loads)

3.4.1. Load match and Grid Interaction indicators[53]

Load Matching refers to how the local energy generation compares with the building load. Grid Interaction refers to the energy exchange between the building and an energy infrastructure, typically, the power grid. These are independent, but intimately related issues. The main distinction made here is that load matching indicators measure the degree of overlap between generation and load profiles (e.g. the percentage of load covered by on-site generation over a period of time) whereas grid interaction indicators take aspects of the unmatched parts of generation or load profiles into account (e.g. peak powers delivered to the electricity distribution grid).

Load cover factor[54] represents the percentage of the electrical demand covered by on-site electricity generation and is defined as:

$$\gamma_{load} = \frac{\int_{\tau_1}^{\tau_2} min[g(t) - S(t) - \zeta(t), l(t)]dt}{\int_{\tau_1}^{\tau_2} l(t)dt}$$

Then a complementary index, the supply cover factor, can be defined representing the percentage of the on-site generation that is used by the building. Mathematically, it could be defined as:

[53] ANALYSIS OF LOAD MATCH AND GRID INTERACTION INDICATORS IN NET ZERO ENERGY BUILDINGS WITH HIGH-RESOLUTION DATA A report of Subtask A IEA Task 40/Annex 52 Towards Net Zero Energy Solar Buildings (to be published)

[54] Jaume Salom, Joakim Widén, José Candanedo, Igor Sartori, Karsten Voss, Anna Marszal, Understanding Net Zero Energy Buildings: Evaluation of Load Matching and Grid Interaction Indicators, Proceedings of Building Simulation 2011, 12th Conference of International Building Performance Simulation Association, Sydney, 14-16 November, pp. 2514-2521, 2011

$$\gamma_{supply} = \frac{\int_{\tau_1}^{\tau_2} min[g(t) - S(t) - \zeta(t), l(t)]dt}{\int_{\tau_1}^{\tau_2} [g(t) - S(t) - \zeta(t)]dt}$$

The ***loss of load probability*** is defined as the percentage of time that the local generation does not cover the building demand, and thus how often energy must be supplied by the grid.

$$LOLP_b = \frac{\int_{\tau_1}^{\tau_2} f(t)}{T} \qquad \begin{cases} f(t) = 1, if\ ne(t) < 0 \\ f(t) = 0, if\ ne(t) \geq 0 \end{cases}$$

3.4.2. Metrics already defined in previous sections

CADE
PUE
DCIE
CPE
DCeP
SI-POM
H-POM
THD
ERF
ERE
CEF
Global KPI of Energy Efficiency
DPPE
TUE
pPUE
KPI_{EC}
KPI_{TE}
KPI_{REUSE}
KPI_{REN}
KPI_{GP}
CCF
DCMM

Code of Conduct
PSRR
Data Centre Measurement, Calculation and Evaluation Methodology (DOLFIN)
Grid Efficiency (All4Green Metric)
GEC

3.5. Lighting - energy / power consumption (loads)

3.5.1. Lighting Density

Proposed by: Lawrence Berkeley National Laboratory[13]

Measures: Ratio of the data center lighting power consumption to the data center area

Measuring unit: unit-less (%)

Calculation Method:

$$Lighting\ Density = \frac{Data\ center\ lighting\ power}{Data\ center\ area} * 1000$$

Where:

- $Data\ center\ lighting\ power$ – power required for data center rooms in *kw*
- $Data\ center\ area$ – data center rooms area in *ft2*

3.5.2. Metrics already defined in previous sections

CADE
PUE
DCIE
CPE
DCeP
SI-POM
H-POM

ERF
ERE
GPUE
Global KPI of Energy Efficiency
DPPE
TUE
pPUE
KPI_{EC}
KPI_{TE}
KPI_{REUSE}
KPI_{REN}
KPI_{GP}
CCF
DCMM
Code of Conduct
PSRR
Data Centre Measurement, Calculation and Evaluation Methodology (DOLFIN)
GEC

3.6. Building - energy / power consumption (loads)

3.6.1. Building Heat Loss[55]

Measures: Total heat loss of a building hosting a data center

Measuring unit: W

Calculation Method:

$$Total\ heat\ loss = H_t + H_v + H_i$$

where:

- H_t - heat loss due to transmission through walls, windows, doors, floors and more (W)

[55] http://www.engineeringtoolbox.com/heat-loss-buildings-d_113.html

- H_v - heat loss caused by ventilation (W)
- H_i - heat loss caused by infiltration (W)

3.6.2. Metrics already defined in previous sections

DCPD
DCD
Global KPI of Energy Efficiency
DPPE
KPI_{EC}
KPI_{TE}
KPI_{REUSE}
KPI_{REN}
KPI_{GP}
CCF
DCMM
Code of Conduct
PSRR
Data Centre Measurement, Calculation and Evaluation Methodology (DOLFIN)
GEC

3.7. Energy produced locally

3.7.1. Weighted energy Balance in Data Centres[56]

Therefore it is identified an energy balance through data centre outer boundaries taking in account delivered energy and feeding energy coming from different energy sources and shown in Figure 5 and formulated in equation below:

$$\sum_i f_i \cdot w_{f,i} - \sum_i d_i \cdot w_{d,i} = F_{DC} - D_{DC} = Bal$$

[56] http://www.coolemall.eu/documents/10157/25512/CoolEmAll+-+D5.1+Metrics+v1.4.pdf?version=1.0

Where,

- f_i is the feeding energy.
- d_i is the delivered energy.

w_i is the corresponding weighting factor depending of the chosen weighting system.

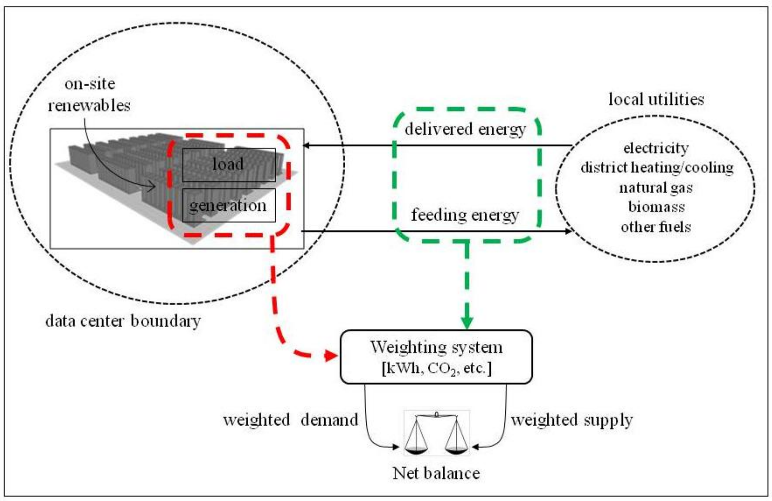

Figure 5. Weighted energy balance in data centres: Source IREC

3.7.2. Metrics already defined in previous sections

CEB
CADE
KPI_{EC}
Load match and Grid Interaction
KPI_{TE}
DCMM
Code of Conduct
Data Centre Measurement, Calculation and Evaluation Methodology (DOLFIN)
Grid Efficiency (All4Green Metric)
GEC

3.8. Heat recovered

3.8.1. Metrics already defined in previous sections

CADE
$Im_{DC,Temp}$
ERF
ERE
Building Heat Loss
KPI_{EC}
Load match and Grid Interaction
KPI_{REUSE}
DCMM
Code of Conduct
Data Centre Measurement, Calculation and Evaluation Methodology (DOLFIN)
GEC
Weighted energy Balance in Data Centres

3.9. Power shifting

3.9.1. Metrics already defined in previous sections

KPI_{EC}
Load match and Grid Interaction
DCMM
Code of Conduct
GEC
Weighted energy Balance in Data Centres

3.10. CO2 emissions

3.10.1. Carbon Credit

Measures: The offset credits that are bought and sold to offset carbon dioxide emissions (similar to paying a fine for noncompliance). The price varies for every country and its regulations.

Calculation Method:

$$1\ Carbon\ Credit = 1\ tonne\ of\ carbon\ dioxide = 1\ tonne\ carbon\ dioxide\ equivalent\ gases = \text{x.xx}\ USD\ or\ EUR$$

3.10.2. Nuclear Emissions (All4Green Metric)

The following metric represents the ratio of nuclear power at the overall energy mix in cases where the energy mix within fossil and nuclear energy sources is affected by All4Green. This is a metric that can be used in addition to the CO2 metric in order to reflect to which degree the CO2 decrease has been traded in by nuclear power.

$$NucP = \frac{kwNucPP}{TotalPower}$$

$$NucE = \frac{kwhNucPP}{TotalEnergyProduced}$$

Where:

- $kwNucPP$ or $kwh\ NucPP$ being the power or energy produced by nuclear power plants and
- $TotalPower$ or $TotalEnergyProduced$ being the total power or energy produced by an EP

3.10.3. CO2 Emissions (All4Green Metric)

$$ESEmission\left(Type_p, \Delta t, kWh, source_s\right) = \sum_s \left(\sum_p EF\left(Type_p\right) * a\left(Type_p\right) * kWh_s \right)$$

Where

- $ESEmission$ are the emissions attributed to one energy supplier
- Δt is the time period in which the values are measured (discrete time slots)
- $source_s$ are the different energy sources (coal, solar, nuclear etc…)
- $Type_p$ are the different types of emissions (CO2, nuclear waste, Sulfur etc. measured in kg)
- $EF\left(Type_p\right)$ is the emission factor per kW of type p for source s
- $a\left(Type_p\right)$ is a factor that gives each type p of emissions its own importance, with SUM_a=1

This formula implies that changes of emissions of one emission type can be outweighed (depending on factor a) by the change of another one. And the merged dimension of this formula is the weight in kg. It is a generic formula, which in All4Green was only applied to CO2 emissions.

3.10.4. Metrics already defined in previous sections

CUE
CEB
WUE
GEC
CEF
CIUD
GPUE
DPPE
KPI_{TE}
KPI_{REN}
DCMM
Code of Conduct

3.11. Performance

3.11.1. Total Cost of Ownership (TCO)

Measures: The cost it takes an owner to purchase or build, operate, and maintain a data center

Calculation Method:

$$TCO = Capital\ Expenses + Operational\ Expenses$$

Where:

- $Capital\ Expenses$ – initial investments for building a data center (cooling, space, servers, etc.)
- $Operational\ Expenses$ – monthly expenses of running a data center (management costs)

3.11.2. Return of Green Investment (RoGI)

Measures: The period of time in which the investments (money, human resources etc.) made in green solutions are recuperated

Calculation Method:

$$RoGI = Months\ or\ Years\ to\ recover\ investments$$

3.11.3. Return on Investment of All4Green for the Energy Supplier (All4Green Metric)

The first ROI metric looks at the All4Green business performance from the energy provider's point of view: only if it proves worthwhile, an ES will undertake the effort to implement the framework. Of course, the results heavily depend on the legal framework within which the EP operates (especially laws, taxes, CO2 certificates).

$$\mathrm{ROI\_All4Green_{ES}} = \frac{\left(CostReductionGreenSDA_{EP} - Sum(Rewards\&PenaltyGreenSDA)\right)}{Sum(Rewards\&PenaltyGreenSDA)}$$

3.11.4. Return on Investment of All4Green for the Data Centre (All4Green Metric)

The second ROI takes the data centre point of view. The DC market is not as heavily regulated by laws and taxes as the energy market so that the dependence on the economic framework is less strong. Also this ROI is complex to calculate and will be more thoroughly be dealt with in WP3.

$$\mathrm{ROI\_All4Green_{DC}} = \frac{\left(Sum(Rewards\&PenaltyGreenSDA) + |\Delta SiteEnergyCost| - Sum(Rewards\&PenaltyGreenSLA)\right)}{Sum(Rewards\&PenaltyGreenSDA)}$$

Note that the $Sum(Rewards\&PenaltyGreenSDA)$ are cost from the point of view of the ES, but "income" from the point of view of the DC. For the DC the cost of the A4G system are the $Sum(Rewards\&PenaltyGreenSLA)$ it has to pay to its customers.

3.11.5. GreenSDA and GreenSLA (All4Green Metric)

The concept of a GreenSDA was researched and implemented in the All4Green system. A GreenSDA is an agreement between an energy supplier and a data centre that defines the scope for the energy supplier to require collaboration from the data centre to increase or reduce its power demand in case of need.

The concept of a GreenSLA, an energy aware service level agreement between the data centre and its customers that increases the scope to manage the data centre in an energy aware way.

3.11.6. Energy cost / price

3.11.7. Metrics already defined in previous sections

DCeP
TPS/Watt
PAR4
DC FVER
ITEU
ITEE
KPI_{EC}
KPI_{GP}
DCMM
Code of Conduct
Data Centre Measurement, Calculation and Evaluation Methodology (DOLFIN)
Energy Consumed by Service (All4Green Metric)
Energy saving vs. Quality of service (All4Green Metric)
Carbon Credit