Data Center Sustainability Indices

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ABSTRACT

Life cycle assessment of data centers has indicated that the main environmental impacts stem from the embodied impacts, energy efficiency and source energy mix of the facility mechanical and electrical systems and equipment and IT equipment. Metrics to describe the in-use efficiency of the power and cooling infrastructure are well adopted, however the other areas often go unmonitored, in part due to lack of data, metrics and difficulty of measurement. Without a holistic view of impact, burden shift may occur, i.e. where action is taken to reduce the environmental impact of one area which moves or increases the impact to another area. Life cycle assessment considers a range of environmental impacts grouped into areas of protection: human health and climate change, ecosystem quality and resources. In this paper a metric comprising separate measures for each main area of impact is described, identifying key variables and analysing their range so that their effect on environmental impact may be understood and used as a basis for decision making. The operational component includes the influence of energy and water consumption, PUE, WUE and renewable energy usage. The embodied component considers variables such as utilization, equipment lifecycle, materials and disposal in mechanical and electrical systems and plant and IT equipment. These are related to the IT output via a productivity proxy. The paper includes preliminary analysis of the application of the metric.

INTRODUCTION

Growth trends in the data center sector suggest that its energy consumption and environmental impact will continue to rise. Sustainability is an issue which has gained prominence amongst consumers, investors and businesses and hence there is a growing interest on understanding the environmental impact of data centers[i]. Best practice low energy / high energy efficiency designs have become mainstream and there is a clear business case for reducing operational energy costs. Power Usage Effectiveness (PUE) is a widely adopted metric used to illustrate the energy performance of a data center facility's power and cooling infrastructure[ii]. It excludes the performance of the ICT systems however, which have a significant impact on the overall data center energy consumption.

To consider environmental sustainability holistically, the whole life cycle of the data center needs to be examined, not just the in use, operational phase. Life Cycle Assessment (LCA) provides a framework for this[iii]. The life cycle of a product or service is analysed from cradle to grave (or cradle to cradle in a circular economy model[iv]); this includes the production and decommissioning stages. The environmental impacts from these stages are referred to as the embodied impacts and include those associated with mining of materials, manufacture of components, transportation, and treatment at end of life. End of life practices include incineration with or without energy recovery and/or sending waste to landfill, also remanufacture, reuse and recycling in a circular economy where product life is extended; however, at present a lot of IT / electrical and electronic waste is not recycled. The range of environmental impacts considered is broad and includes not only carbon dioxide emissions but other emissions and damage to air,

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water and soil.

These may be weighted and their impact quantified as Eco-points using the Eco-indicator 99 method, where 1000 points (Pt) equate to the environmental impact of an average European person per year. This allows different categories of environmental impact to be compared and assist decision making. The Eco-indicator 99 method[v] is one of the most widely used impact assessment methods in LCA. It is the successor of Eco-indicator 95, the first endpoint impact assessment method, which allowed the environmental load of a product to be expressed in a single score. Each method (midpoint, endpoint) contains factors according to the three cultural perspectives. These perspectives represent a set of choices on issues like time or expectations that proper management or future technology development can avoid future damages:

- **Individualist**: short term, optimism that technology can avoid many problems in future.
- **Hierarchist**: consensus model, as often encountered in scientific models, this is often considered to be the default model (used in this analysis)
- **Egalitarian**: long term based on precautionary principle thinking.

Results will vary according to weighting set; the average / default set has been used for this model.

Without taking a holistic view, some significant impacts may not be visible and there is a risk of burden shift. For example by just focusing on the operational phase, components may be replaced by more efficient ones thereby reducing energy consumption, however the embodied impact will have increased (to maybe more than double). Without analysis, it is not possible to assess whether the improvement in energy performance sufficiently offsets the increased embodied impact.

Previous data center LCA studies[vi,vii] have found that operational energy use is significant and so is the embodied impact of ICT equipment and the mechanical and electrical (M&E) installation, and the source energy mix for the operational and embodied phases. The embodied impact of the building (fabric etc.) was found to be relatively insignificant and hence it has been excluded from the equation in this paper.

Detailed LCA studies are resource intensive, particularly for analyzing a system as complex as a data center with its large inventory of parts and subsystems. However, previous findings may be used as a basis for guidelines for improving environmental performance without necessitating a full LCA for every facility.

This work has allowed the development of a compound metric which incorporates all of the key elements of environmental impact (both operational and embodied) and allows users to better understand their interaction. The work to date is indicative and this first version of the sustainability index has been developed to illustrate the relative effect that different factors can have on the overall sustainability of a data centre; these may change as further data becomes available.

The metric comprises several elements and incorporates some existing metrics, each of which are examined in the following sections; examples of its application in various scenarios are then analysed.

SUSTAINABILITY INDEX

The data center sustainability index may be defined as follows:

Simplified equations to be added (so obvious op + emb)

$$SI = \frac{P_{IT}}{bits}\left[8760(PUE \cdot iel + WUE \cdot iw + WD \cdot id) + i_{IT} \cdot f_{IT}\left(\frac{3}{L_{IT}}\right)\left(\frac{0.1}{U_{IT}}\right)D_{IT} + PUE \cdot i_{ME} \cdot f_{ME}\left(\frac{15}{L_{ME}}\right)\left(\frac{0.3}{Pl_{ME}}\right)D_{ME}\right]$$

Where:

SI = Sustainability Index (Pt/Mb)

Useful work proxy
P_{IT} = power used by IT equipment (kW)
bits = outbound router traffic leaving data center (Mb)

Operational electricity index
PUE = Power Usage Effectiveness
i_{el} = impact of electricity (Pt/kWh)

Operational water index
WUE = Water Usage Effectiveness (L/kWh_{IT})
i_w = impact of water (Pt/L)
WD = water discharged (L/kWh_{IT})
i_d = impact of water discharged (Pt/L)

Embodied IT index
i_{IT} = embodied impact of IT equipment (Pt/kW_{IT})
f_{IT} = IT factor
L_{IT} = lifetime of IT equipment (years)
U_{IT} = % utilization of the IT equipment
D_{IT} = IT design

Embodied M&E index
I_{ME} = embodied impact of M&E systems (Pt/kW_{IT})
f_{ME} = M&E factor
L_{ME} = lifetime of M&E systems (years)
Pl_{ME} = part load of M&E systems
D_{ME} = M&E design

USEFUL WORK

When quantifying data center performance, a measure of 'useful work' is required. However it is difficult to find a universal metric which can describe this for all facilities – the functions and outputs of IT services are highly variable and serve different business functions.

Datacenter ICT may be categorized into three elements (with units of output vs energy use in brackets):

- Processing (TFlops/W)
- Network (Gbs/W)
- Storage (GB/W)

The balance between the different elements and performance will vary across different types of facilities, e.g. High Performance Computing compared with web hosting.

The Green Grid describe several metrics which may be used as proxy measures of data center productivity[viii]. In this case, proxy number 4: Mbits per kilowatt-hour (Mb/kWh) has been incorporated into the SI metric. This is calculated using the total bits of data leaving the data center on all outbound routers during an assessment window and dividing by the total data center energy consumption during the same period. It is relatively simple and inexpensive to measure. The metric indicates efficiency improvements when bits out increase or remain the same and energy consumption reduces. However, it is possible that some improvements in IT performance are not captured by this metric (there may not be a direct correlation with bits out or power consumed).

OPERATIONAL ELECTRICITY INDEX (SI_{EL})

This index describes the environmental impact of energy consumption during the use phase of the data center.

Power used by IT equipment (P_{IT}) is the annualized value of kW based on the energy consumption from the last 12 months (kWh/8760 hours).

The environmental impact of electricity production (i_{el}) data has been extracted from the EcoInvent 2006 database v2.2 and varies for each country, depending on the grid mix (renewables have less impact).

OPERATIONAL WATER INDEX ($SI_W + SI_{WD}$)

This index describes the environmental impact of water during the use phase of the data center.

WUE[ix] measures water consumed by the facility but excludes water discharged and treated offsite.

The environmental impact of tap water (i_W) data has been extracted from the EcoInvent 2006 database v2.2. A figure of 0.000018Points/litre has been used for all countries in the analysis, however in reality this would vary and more recent data is likely to indicate a higher impact, due to increasing water stress. Pfister et al describe a comprehensive methodology for evaluating the environmental impacts associated with water use[x].

It has been assumed that half of the water consumed on site is evaporated and hence the remaining half is discharged to drain (hence WD is half of WUE).

Discharged water has a far higher environmental impact than tap water, as it requires processing (including dilution) to be converted from grey water back to clean water. A factor of 250 has been assumed based on analysis from a previous paper[xi], hence discharged water has 125 times the impact of water consumed. (analogy due to need to dilute grey to blue). In reality the type of water treatment undertaken both on and off site would have different impacts.

EMBODIED IT INDEX (SI_{IT})

This index describes the embodied impact of data center IT equipment.

A value of 587Pt/kW$_{IT}$ has been assumed for i_{IT}, this is derived from previous research[xii].

The IT factor (f_{IT}), may be used to adjust the embodied impact of IT if it is estimated to be better or worse than the base case. Improvements to the IT equipment manufacturing and recycling processes and reducing transport distances of components are examples of how this impact might be reduced.

The basecase uses an average three year life for IT equipment. This may be adjusted up or down (L_{IT}) which will be reflected in the impact.

The basecase assumes a 10% utilization of IT equipment. This may be adjusted based on the real value (U_{IT}), for example, highly virtualized environments have higher utilization.

IT design (D_{IT}) is a factor which relates to design decisions associated with IT equipment which impact the embodied impact. For example, dematerialization (particularly relating to hotspot metals in printing wiring boards) would reduce this factor. Other examples are selecting devices with no case, IT racks without side panels or doors and replacing materials with lower impact ones.

EMBODIED M&E INDEX (SI_{ME})

This index describes the embodied impact of data center M&E equipment.

A value of 189Pt/kW$_{IT}$ has been assumed for i_{ME}, this is derived from previous research[xii].

The M&E factor (f_{ME}), may be used to adjust the embodied impact of M&E if it is estimated to be better or worse than the basecase. Improvements to the manufacturing process, use of refurbished plant and reducing transport distances of components are examples of ways the impact might be reduced.

The basecase uses an average 15 year life for M&E equipment (L_{ME}). This may be adjusted up or down which will be reflected in the impact.

The basecase uses an average 0.3 year part load for M&E systems ($PL_{M\&E}$). This is a reflection of the design topology, i.e. redundant distribution streams and components. For a 2N system with redundant distribution, the part load would not exceed 50% under normal operating conditions, in reality is it unlikely to exceed 40%.

M&E design (D_{ME}) is a factor which relates to design decisions associated with M&E systems which impact the embodied impact. For example, dematerialization through the use of free cooling, use of plant which is normally not-operating (generators and fuel system).

PRELIMINARY ANALYSIS

Table 1 summarises the results for a number of different scenarios in different locations:

Parameter	Units	Range	UK, Croatia, Spain (Basecase)		Sweden/France	Ireland
iel	Pt/kWh	0.006-0.23 (country specific)	0.115		0.025	0.18
Pit	kW		1		1	1
bits	Mb		1		1	1
PUE		1.1 to 3	1.8		1.8	1.8
WUE	L/kWh it	0 to 10	5		5	5
iwtr	Pt/l		0.000018		0.000018	0.000018
WD	L/kWh it	0 to 10	2.5		2.5	2.5
id	Pt/L		0.0045		0.0045	0.0045
iit	Pt/kWit		587		587	587
fit		0.25 to 4	1		1	1
Lit	yrs	0.5 to 10	3		3	3
Uit		0.02 to 1	0.1		0.1	0.1
Dit		0.5 to 3	1		1	1
ime	Pt/kWit		189		189	189
fme		0.05 to 2	1		1	1
Lme	yrs	5 to 25	15		15	15
Plme		0.1 to 1	0.3		0.3	0.3
Dme		0.5 to 3	1		1	1
SI	Pt/Mb		2840		1421	3865
SI el			1813	64%	28%	73%
SI w			0	0.01%	0.03%	0.01%
SI wd			99	3%	7%	3%
SI it			587	21%	41%	15%
SI me			189	7%	13%	5%
Op/Emb				2.46	0.64	3.79

Table 1 Summary of scores for different scenarios

Graphs to be added

For the locations analysed with the stated assumptions, in countries with a relatively high fossil fuel content in the electricity grid, the operational phase dominates due to the relatively high impact of electricity use; the embodied impact of IT equipment is the next most significant element. In countries with a high renewable grid mix, the embodied impacts are larger than the operational and these two elements are reversed in significance.

If the impact of discharged water was 1000 times that of tap water (four times higher than currently assumed), this would increase its impact significantly: in Sweden / France it would rise to 23% of the total impact, for the others 9-13%.

Further analysis was undertaken to compare the scenarios above with a best case scenario for each location (using the minimum / maximum value of the range as applicable). This allows the parameters which have the highest improvement impact on SI to be identified.

Table 2 ranks the parameters in order of improvement impact compared with the basecase for each location:

Location	Sweden/France	UK, Croatia, Spain	Ireland
Ranked parameters with 1 sigma (68%) cumulative improvement impact	U_{IT} f_{IT} L_{IT} i_{el} f_{ME} D_{IT}	i_{el} PUE U_{IT} f_{IT}	i_{el} PUE U_{IT}
Additional ranked parameters to 2 sigma (95%) cumulative improvement impact	PUE Pl_{ME} D_{ME} L_{ME}	L_{IT} f_{ME} D_{IT} Pl_{ME} D_{ME}	f_{IT} L_{IT} f_{ME} D_{IT} Pl_{ME} D_{ME}

Table 2 Ranked improvement parameters

In all cases IT utilization and the impact of electricity are in the 1 sigma range. In Sweden and France, all of the embodied impact of IT equipment variables feature in the 1sigma range. In other locations, the impact of PUE ranks more highly than some embodied IT parameters.

Many of the parameters are interrelated and need to be considered concurrently to avoid the burden shift issue. For example, when making a change relating to IT equipment this will impact more than one if not all of the following parameters: P_{IT}, f_{IT}, D_{IT}, bits, L_{IT}, U_{IT}. Hence the following equation, extracted from the SI may be used to evaluate whether the projected final state (subscript 1) has a reduced impact compared with the starting state (subscript 0); a value of less than one would indicate an improvement in environmental impact.

$$\frac{P'_{IT}}{P^{\emptyset}_{IT}}\frac{f'_{IT}}{f^{\emptyset}_{IT}}\frac{D'_{IT}}{D^{\emptyset}_{IT}}\cdot\frac{bits^{\emptyset}}{bits'}\frac{L^{\emptyset}_{IT}}{L'_{IT}}\cdot\frac{U^{\emptyset}_{IT}}{U'_{IT}}<1$$

The same principle can be applied for M&E related changes with this equation:

$$\frac{P'_{IT}}{P^{\emptyset}_{IT}}\frac{f'_{ME}}{f^{\emptyset}_{ME}}\frac{D'_{ME}}{D^{\emptyset}_{ME}}\cdot\frac{bits^{\emptyset}}{bits'}\frac{L^{\emptyset}_{ME}}{L'_{ME}}\frac{PL^{\emptyset}_{ME}}{PL'_{ME}}<1$$

CONCLUSIONS AND NEXT STEPS

The SI metric allows the total environmental impact of data centers to be quantified; it includes both operational and embodied impacts and identifies which areas have the highest contribution to total impact. This tool may be applied to identify priorities for improvement and assess the impact of a proposed change for a specific data center depending on its characteristic parameters. It assists with decision making allowing users to understand the total impact of an change in one area by quantifying the delta between the before and after state without having to undertake a full LCA, but benefiting from findings of previous studies.

Initial findings suggest the following improvements to be significant:

- Increasing utilization of IT (achieved via consolidation and virtualization)
- Using a more renewable energy source
- Minimizing PUE. The largest opportunities may be founding in optimizing of cooling systems and

scalability at part loads[xiii].

- Reducing the embodied impact of IT equipment (predemoninantly through the product design and manufacturing and end-of-life processes)
- Assessing when IT equipment refresh results in a reduced overall impact. This topic is explored in a paper scheduled for publication[xiv].
- Considering overall resilience and removing excessive levels across IT and M&E systems (e.g. through virtualization)

These could be used as green procurement criteria.

A number of best practice recommendations which support these improvements are available in the European Code of Conduct for Data Centre Energy Efficiency[xv] and EN50600[xvi] Technical Report 99-1. Technical Report 99-2 (in development) will incorporate further recommendations associated with the embodied rather than the operational impacts.

Although the impact of discharged water appears to be relatively low in this results set, it is thought that the input data used underestimates the true impact. Its impact could be reduced by minimizing the volume of water discharged, for example by examining opportunities for increased water reuse on site (subject to any offsets resulting from increased embodied impacts from such a system).

Further work on validating the proposed model with additional data sets is needed, including testing with data from real facilities. The variability in database source introduces a level of uncertainty to the results (especially for water). The limitations of the bits out proxy for useful work metric also requires further examination, to understand for example how it varies for different for types of data center.

Maximum length 8 pages excluding references

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NOMENCLATURE

think we need this section? Feels like it is an unnecessary repeat

β = don't panic

Δ = your trusty towel

V = Vogan poetry

G_1 = infinite improbability drive

X_t = time it takes to bulldoze one Earth to make way for an Intergalactic Superbypass

Subscripts

a = life

b = the universe

c = everything

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[xv] European Commission JRC, 2017 Best Practice Guidelines for the EU Code of Conduct on Data Centre Energy Efficiency v8.1.0.

[xvi] EN50600 Data Centre standard series for infrastructures and facilities