OPEN DATA CENTER ALLIANCE℠ USAGE MODEL: CARBON FOOTPRINT AND ENERGY EFFICIENCY REV. 2.0

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EXECUTIVE SUMMARY

According to market research and consulting firm Pike Research, data centers around the world consumed 201.8 terawatt hours (TWh) of electricity in 2010 and energy expenditures reached $23.3 billion. That's enough electricity to power 19 million average U.S. households. The good news is that the adoption of cloud computing could lead to a 38-percent reduction in worldwide data center energy expenditures by 2020.[1]

As data center footprints expand and energy consumption rises, organizations are increasingly under pressure to reduce the cost of their operations, and to report and reduce their environmental impact. In many regions of the world, governments and corporations now require a measurement of the carbon[2] footprint of services and products. For example, the Carbon Disclosure Project[3] is persuading businesses to issue Corporate Responsibility Reports that include carbon reporting.[4] In some legislations, such as those in Australia and the United Kingdom, there are already levies for large-scale electricity use, and carbon footprints are gaining significant attention in some regions.[5]

There are regional variations in both how electrical power is generated and distributed, and in the regulations and reporting regarding carbon generation. However, a ton of CO2 is the same wherever it is produced, and it all ends up in the same atmosphere: the climate does not recognize national or political borders. This document is written primarily from a perspective of the United States, Europe, and Australia, but it does make some provision that encompasses other regional variations.

Reducing the amount of electrical energy wasted in business operations can be a win-win proposition for both businesses and the planet. But doing so at the data center level requires an understanding of how technology platforms consume electrical resources.

The Open Data Center Alliance (ODCA) recognizes the growing requirement to indicate the carbon footprint of services and products, for which there are known methodologies[6] of measurement and assessment. But some IT services are delivered as a "black box" from the cloud, or even just outsourced, making carbon footprint assessment difficult. What's more, it is generally accepted nowadays that an organization cannot jettison its carbon impact by simply having someone else take it over. The usage model presented later in this guide is designed so that organizations can predict CO_2 emissions and track actual emissions through technical capabilities instituted by providers of cloud services. And while it is obvious that drawing energy from green sources, such as hydroelectric and solar energy, can create the smallest possible carbon footprint, such an option is not available for every data center and cloud. So while ODCA encourages the use of green power, in reality it is the most efficient use of power being generated by any means that can have the largest effect on such a footprint today.

This document serves a variety of audiences. Business decision makers looking for specific solutions and enterprise IT groups involved in planning, operations, and procurement will find this document useful. Solution providers and technology vendors will benefit from its content to help them better understand customer needs and tailor service and product offerings. Standards organizations will find the information helpful in defining standards that are open and relevant to end users.

This document relies, in part, on the work of The Green Grid, which provides many of the facts and methods to back up our good intentions.

[1] See the December 6, 2010 report from Pike Research at www.pikeresearch.com/newsroom/cloud-computing-to-reduce-global-data-center-energy-expenditures-by-38-in-2020

[2] There are more greenhouse gases than just carbon dioxide, such as methane, but carbon seems to be generally accepted as the one that is a most prevalent by-product of the use of IT.

[3] See the Carbon Disclosure Project: www.cdproject.net

[4] At the time of writing, the Sustainability Accounting Standards Board (www.sasb.org) is about to launch an exercise intended to standardize sustainability accounting for publicly-listed corporations in the United States.

[5] The European Commission is working with 27 leading tech companies and associations in an attempt to measure the carbon footprint being generated from production, the transport and sales of ICT goods, networks, and services: www.neurope.eu/article/technology-sector-measure-carbon-footprint

[6] The World Resource Institute (www.wri.org) and the World Business Council for Sustainable Development (www.wbcsd.org), who built the Greenhouse Gas (GHG) protocol, the global standard for carbon footprinting, are working with the Global eSustainability Initiative (www.gesi.org) to produce a robust and globally standardized methodology for footprinting data.

PURPOSE

This usage model establishes an open and standard approach for measuring the carbon footprint of services provided from the cloud. Along with the "Standard Units of Measure" (SUoM) already defined by the ODCA,[7] the amount of CO_2 created should be provided within a Service Catalog and measured based on recognized standard approaches that are sufficiently verifiable. It is also expected that a multi-vendor and consistent approach across data center providers be available for cloud subscriber review.

It is expected that providers of cloud services offer access to the CO_2 measure in several ways.

- Within the Service Catalog, attached to price lists, so as to allow prediction and comparison of CO_2 emissions for standard units of compute capacity (for example, CPU, core, MIPS, or GB)
- Actual amounts summarized to customers via a portal and/or with their monthly bill, allowing analysis of trends over time and comparison with other cloud providers
- Details of how the net CO_2 emissions are calculated (that is, power generated by hydroelectric, wind, solar energy,[8] coal, or gas, versus the purchase of CO_2 offsets/credits[9])

The measure will allow the organization subscribing to the cloud services to do the following:

- Assess and compare the relative efficiency and sustainability of competing cloud providers
- Consider either shifting the workload to other suppliers with a lower footprint, or to low-carbon regions and countries (where acceptable), or applying "follow-the-moon" techniques
- Analyze carbon production over time to aid in planning and implementation of green IT policies
- Provide audits and reports to corporate and regulatory bodies on their green initiatives and carbon profiles

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7 See www.opendatacenteralliance.org/library

8 The full calculation of emissions from power generation must be understood; that is, where power from wind and solar still has to have coal (or other conventional) power sources running as backup, to cater for the intermittent nature of these sources, that needs to be included in the calculation. Normally, such statistics are available from the power supplier.

9 Full disclosure is required from the service provider. For example, if a site is carbon neutral simply by purchasing carbon credits, the power consumed may not really be carbon neutral. The creation and sale of carbon credits is a transfer of money and unless "additionality" is guaranteed, it cannot be seen as proof of clean energy.

TAXONOMY

Table 1 lists the standard terms and definitions used in this document.

Table 1. Terms and definitions.

Actor	Description
Auditor	External agencies and individuals who perform audits over a specific area or market.
Carbon Disclosure Project	An independent, not-for-profit organization working to reduce greenhouse gas emissions and increase sustainable water use by business and cities.
Carbon Footprint	A measure of the total amount of carbon dioxide (CO_2) and methane (CH4) emissions of a defined population, system, or activity, considering all relevant sources, sinks, and storage within the spatial and temporal boundary of the population, system, or activity of interest. This is calculated as a carbon dioxide equivalent (CO_2e), using the relevant 100-year global warming potential (GWP100).
Cloud Infrastructure Environment	A cloud provider's specific implementation of hardware, software, management infrastructure, and business processes and practices to implement a provider's service catalog.
Cloud Provider	An organization providing cloud services and charging cloud subscribers. A cloud provider provides services over the Internet. A cloud subscriber could be its own cloud provider, such as for private clouds.
Cloud Subscriber	A person or organization that has been authenticated to a cloud and maintains a business relationship with a cloud.
EEE	Electronics and electrical equipment
Decommissioned EEE	Electronics and electrical equipment (EEE) that leaves the control of the organization.
EOCU	End of Current Use. The equipment is no longer being used for its last-identified purpose. If a piece of IT EEE is going to be repurposed or reused within an organization, that piece of IT EEE should not be considered in metric calculations.
EOL	End of Life. When used to describe computing equipment, EOL means an individual piece that is no longer suitable for use and is intended for dismantling and recovery of spare parts, or is destined for recycling or final disposal. It also includes off-specification or new computing equipment that has been sent for recycling or final disposal.
Infrastructure as a Service (IaaS)	A model of service delivery whereby the basic computing infrastructure of servers, software, and network equipment is provided as virtualized objects, controllable via a service interface. Organizations can use this infrastructure to build a platform for developing and executing applications, while avoiding the cost of purchasing, housing, and managing their own components.
Legislator/Law Enforcement	Entity that creates, enacts, and/or enforces laws.
Metering	The monitoring, controlling, and reporting of resource usage, at some level of abstraction appropriate to the type of service (for example, storage, processing, bandwidth, or active user accounts). Metering enables both the provider and consumer of the service to control and optimize usage.
UEEE	Used electronics and electrical equipment.
WEEE	Waste electronics and electrical equipment.

POLITICAL ACCEPTANCE

There is a broad range of attitudes toward the relevance and impact of carbon generation, from full acceptance of responsibility to complete denial. And between those extremes are those who are willing to accept such measurements as a financial indicator. This differs per region of the world, and even per country. In many countries legislations are beginning to require reporting of emissions if not the actual reduction of carbon emissions.

There is also an increased expectancy that companies be good corporate citizens and include Corporate Social Responsibility (CSR) or triple bottom line reporting (reporting on economic, community, and environmental performance) in annual reports.

In any case, producing electricity from green sources and reduction of its use is a win-win: it both reduces environmental impact and lowers costs.

The audience for such savings may also vary: carbon impact is mostly of interest to regulatory bodies, whereas financial cost is primarily of interest to the involved businesses themselves and their shareholders.

Similarly, the expectation, take-up or acceptance of CSR reports varies in different regions. This can create reporting issues for multinational companies but software products are now available that cater to the differing requirements and allow reporting based on country. Collecting the base data is still a time-consuming business.

USAGE MODEL DIAGRAM

Figure 1 shows the major components of the carbon footprint usage model. The diagram includes both the carbon embedded within the equipment, at both manufacture and disposal stages, and that generated by its use; both are described in more detail in the following text.

Of the IT equipment within a typical data center, 65 percent of the power is used by servers, 20 percent by storage, and 15 percent by the network. Beyond that, there is typically major overhead in running the cooling and power supplies within a data center; this overhead is captured within the Power Usage Effectiveness (PUE) figure for the data center, as described later. There are other components, such as lighting, consoles, and people, but their effect is minimal and tends to appear in the overhead elements, identified in the PUE.

The PUE of a data center varies enormously due to a number of factors, including the age and efficiency of the infrastructure equipment, its configuration and usage, and the environmental conditions.

Note that generators, when used within a data center, will also be a source of carbon emissions and should be incorporated into the carbon emissions reporting. In some countries, generators are used much or even all of the time, due to the unreliability of grid supplies, whereas in others they are exercised only periodically to ensure that they would still function in the unlikely event of a grid failure.

There are moves within many data centers to reuse the excess heat, for instance to heat offices, local houses, or even swimming pools. No attempt has been made to include the effects of such use in the calculations of the carbon footprint.

Equally, the scope of this document is the data center itself: we do not attempt to include the carbon footprints of people traveling to work in such data centers, or of the end users and their equipment, making use of the data center from remote locations.

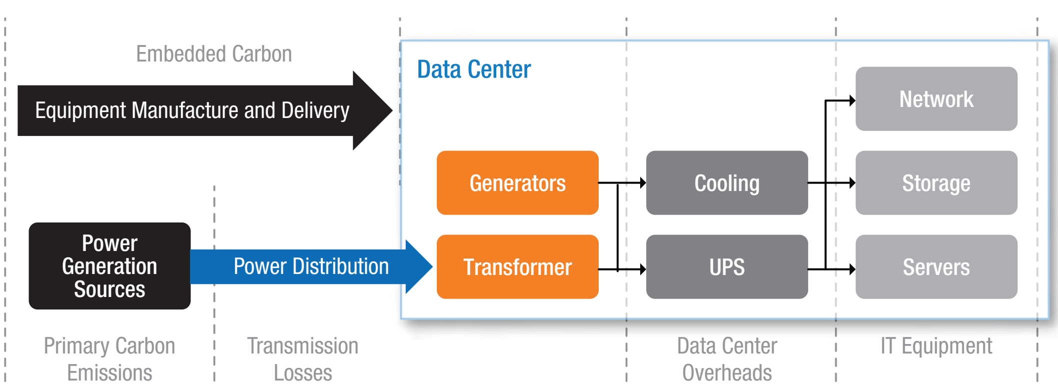

Figure 1. Major components of the carbon footprint usage model.

EMBEDDED CARBON

There are two stages at which the carbon generated by the manufacture of IT equipment is relevant:

Manufacturing and commissioning

The quantities can usually be tracked throughout the supply chain: from component (for example, chip) manufacturers, to hardware suppliers/OEMs, to service providers. These values can be included in the usage figures by amortizing them over the expected useful life/depreciation period of the equipment.

De-commissioning and disposal

"Responsible" decommissioning and disposal of IT equipment can lead to several gains, including the transformation of IT "waste" into an IT "resource," and make a positive impact on the organization's bottom line.

Electronic Disposal Efficiency (EDE) is a metric[10] proposed by The Green Grid to measure the efficiency of disposal of IT equipment. EDE aims to extend the life of used IT EEE and maximize recycling of materials while minimizing the quantity of material delivered to final disposal and the impact on the environment at each stage of the reuse and EOL processes. The EDE promotes the responsible disposal of IT equipment at EOL or EOCU.

EDE, as defined in the "Electronics Disposal Efficiency (EDE): An IT Recycling Metric for Enterprises and Data Centers" white paper, is the total weight of decommissioned IT EEE at its EOCU or EOL that is managed through known responsible entities divided by the total weight of decommissioned IT EEE at its EOCU or EOL:

$$EDE = \frac{Wt_{\text{“Responsibly Disposed”}}}{\text{Total } Wt_{\text{“Disposed”}}}$$

In all cases, EDE ≤ 100 percent. Calculating the EDE requires an organization to both know the weight of those products and components that have been decommissioned, and to identify the destination for those products and components as they leave its control.

When applied to the EDE metric, the term "responsible" means that the management processes referred to above adhere to standards that minimize the possible environmental impact of the IT EEE's disposal and maximize the recovery of embedded materials. Equipment management processes should seek to maximize the recovery of usable components, materials, and energy before resorting to final disposal, and do it in a way that prevents impacts to the environment and human health. Additionally, IT EEE at EOL or EOCU can also be wholly or partially "reused" at a system level (the IT asset is operationally reused and subsequently disposed of responsibly), part level or component level.

It should be noted that security is a crucial consideration when selecting a partner to handle the reuse, recycling, and/or disposal process. In some instances, proper data destruction, such as destruction that is conducted according to the National Institute of Standards and Technology (NIST) guidelines SP800-88,[11] may be possible only through physical destruction of data-carrying devices, which may have an impact on the ability to reuse or recycle the affected IT EEE. The EDE metric assumes that all security considerations appropriate for the organization have been addressed.

Annual reporting against the EDE metric is assumed to be of value to the organization.

The ODCA supports the belief promoted by The Green Grid that the electronics disposal efficiency (EDE) metric will incentivize positive behavior and influence change on a global scale. When IT EEE reaches its EOCU and EOL, which may be well past its depreciation age, organizations should have established management processes that extend the life of used IT EEE and maximize recycling of materials, while minimizing the quantity of material delivered to final disposal and the impact on the environment at each stage of the reuse and EOL processes.

In order to promote responsible disposal of EOCU and EOL IT EEE on a global basis, metrics should be international and used by all corporate consumers and IT EEE manufacturers.

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[10] The Green Grid, "Electronics Disposal Efficiency (EDE): An IT Recycling Metric for Enterprises and Data Centers," White Paper #53.

[11] See www.nist.gov

Responsible management of EOCU and EOL IT EEE should help to minimize corporate risk, including:

- Brand/reputation damage if EOCU or EOL IT EEE is found to harm human health or the environment
- Data loss or misuse
- Disruption of supply chain or site operations
- Decreased credibility in the marketplace
- Decreased shareholder value
- Fines and penalties from regulatory authorities

USAGE MODEL DETAILS

Two related concepts—energy efficiency and the carbon footprint—may be reflected respectively in the costs and climate impact of services. Energy efficiency is to be encouraged, but that factor is also addressed elsewhere, especially in the cost of services. The carbon footprint assessment described herein deals with the key indicator of carbon emission.

The two indicators are not synonymous. When a data center uses green or carbon-neutral energy from a wind turbine or nuclear power, the carbon footprint of the power source may be low, apart from the manufacture of the generating plant itself, but any energy storage and transmission losses associated with such sources certainly are to be included. The use of such "green" sources[12] does not mean, though, that the cloud provider has an energy-efficient data center.

With carbon offsetting, there is debate as to whether it is acceptable or not. The method provided here, therefore, allows for a number of values to be measured: the energy used, the proportion of renewable energy, and whether the residue is offset or not. The cloud provider must provide transparency so the cloud subscriber can be satisfied that it is receiving valid figures.

The method of assessing the carbon footprint depends on obtaining and combining data from a number of internal and external sources. There is no globally accepted and universally applicable methodology, but well-understood and agreed-upon approaches are being followed while methods are being developed.

The amount of carbon produced can be derived from the following formula:

$$\left[\begin{array}{l}\textit{amount of IT equipment}\\ \textit{used, in Standard Units}\end{array}\right] \times \left[\begin{array}{l}\textit{kWh electricity}\\ \textit{used per Unit}\end{array}\right] \times \left[\begin{array}{l}\textit{energy overhead}\\ \textit{of data center}\end{array}\right] \times \left[\begin{array}{l}\textit{carbon emissions of}\\ \textit{of electricity source(s)}\\ +\ \textit{transmission losses}\end{array}\right]$$

Other considerations include the following:

- The Standard Units of Measure (SUoM) could be conceptualized and established for 'the numbers of servers or gigabytes of storage used.[13]
- The electricity used per unit should not just be a "nameplate" value, because that is a maximum figure and does not indicate a real figure for normal use. For servers, the amount of electricity used tends to be around 45 to 50 percent of the nameplate value. In a virtualized environment, it is likely to have to be apportioned.
- The energy overhead of a data center is usually expressed as the PUE, as defined by The Green Grid.[14]
- The Carbon Emission Factor (CEF) is the amount of CO_2 emitted in kilograms (kg) per unit of kilowatt (kW) energy. It is usually obtainable from data published by local governments.

The Green Grid combines the PUE and the CEF to create the Carbon Usage Effectiveness (CUE).[15]

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[12] Even when electricity is produced by thermodynamics (for example, as it is in Iceland), hydroelectricity, or wind farms, and all those sources end up being distributed by the grid, along with power based on coal and nuclear, deriving a carbon emission for that composite electricity is difficult , because you can't tell where any specific electron was produced. However, electricity suppliers can ensure that the relevant proportion of electricity going into and out of the grid indeed came from the intended sources. And having users demanding such sources encourages the providers to produce more electricity from those responsible sources.

[13] The SUoM document describes the need for a standard unit for IT equipment used. What matters for most customers is the carbon generated from running their particular application workload.

[14] See the "Green Grid Data Center Power Efficiency Metrics: PUE and DCiE." www.thegreengrid.org

[15] See the "Carbon Usage Effectiveness (CUE): a Green Grid Data Center Sustainability Metric" white paper #32. www.thegreengrid.org/

The CUE indicates how much total energy is used. The amount of carbon emissions produced will depend on whether renewal sources were used and/or whether carbon was offset. Therefore, cloud providers should be prepared to disclose the energy figure in kW, the amount of carbon produced, and a rationale of kW value.

Costs may arise from IT equipment usage in some countries, such as in the United Kingdom, where taxes are under consideration for high-level power users. These usage taxes may be embedded in the cloud provider's charges or declared explicitly.

Cloud providers should provide energy use and carbon emission figures to their cloud subscribers, using the methods described. And cloud subscribers should demand them, if not already provided. Cloud subscribers should accumulate and aggregate the data for carbon reporting. Using and reporting these figures will likely become a necessary part of doing business in the near future.

Among various cloud subscribers, each will use only a portion of a cloud provider's data center, and they themselves may use multiple providers. Therefore, cloud providers must have methods for allocating carbon usage to specific cloud subscribers. And cloud subscribers must have methods for aggregating the amount of carbon used from various cloud providers and from in-house production. Carbon usage services can be billed as they are at other utility companies.

Any approximations used, and the degree of variances, should be registered and taken into account, so that cloud subscribers can be made aware of them.

The efficiency of data centers, as represented by the PUE, is one major aspect of IT infrastructure efficiency, with the "1.0" on which it is based often being taken as a given. However, attention is also needed regarding the efficiency and use of the IT equipment itself, thus reducing the absolute value of that 1.0 within the PUE. This could be done by a number of methods, including managing their utilization, as described further within this document.

USAGE SCENARIOS

Goals

Assist cloud subscribers with the ability to predict CO_2 emissions and to track and record actual emissions produced on their behalf. The cloud provider must have the technical capability to predict and track these emissions in an auditable manner.

Assumptions

Assumes Standard Units of Measure (SUoM) as documented by the ODCA.

Success scenario 1 (pre-usage)

The cloud provider is able to provide accurate estimates of potential CO_2 emissions associated with all offered services, take steps to minimize them, and ensure that cloud subscriber requirements are met over the mid-to-long term. As part of the Service Catalog, the cloud subscriber is notified of the predicted levels of CO_2 emissions per offered service component, based on SUoM.

Failure condition 1

The cloud provider is unable to identify the sources of CO_2 emission that will arise through use of the hosting infrastructure and/or estimate the volume and rate of CO_2 arising from each use of the infrastructure.

Success scenario 2 (actual, instrumented)

The cloud provider is able to monitor actual CO_2 emissions. The cloud subscriber is notified of the actual levels of CO_2 emissions, at an agreed-upon reporting interval, within acceptable bounds.

Failure condition 2

The cloud provider is unable to identify the sources of CO_2 emission that will arise through use of the hosting infrastructure, and/or quantify the volume and rate of CO_2 arising from each use of the infrastructure.

Failure condition 3

The cloud provider reports the volume and rate of CO_2 arising from each use of the infrastructure, but the figures are significantly outside the predicted levels and there is no reasonable explanation.

Failure condition 4

The cloud provider is unable to allocate the volume and rate of CO_2 arising from use of the infrastructure to specific cloud subscribers.

Failure handling

For all failure conditions, the cloud provider should notify the cloud subscriber of the inability to provide CO_2 emission figures.

Requirements

The existence and use of a Service Catalog, including one with SUoM.

USAGE REQUIREMENTS

This document covers the running of a system, once it and the data center in which it runs have been put in place. It also addresses the full lifecycle of the equipment and the embedded carbon inherent in its production. Both of those considerations require an analysis of when it is advantageous to replace a system with one that is more efficient.

The values and associated costs are expected to vary between providers of cloud services for the following reasons:

- Energy efficiency of hardware used
- Settings of hardware and systems software, including the degree of virtualization and efficiency of its management
- Ambient environmental conditions (for example, Nordic versus Mediterranean)
- Efficiency of data center infrastructure and housing (that is, PUE)
- Source of electricity used (for example, coal versus nuclear from grid, local generators)
- Carbon offsetting and trading options deployed
- National or regional regulation or tax arrangements

Many values and associated costs can also vary from time to time for any one provider. For example, PUE values fluctuate seasonally, due to weather and ambient temperatures.

This document does not prescribe in detail how any of these factors can be improved. There are many sources within the IT industry that provide information on how that can be done. A good, comprehensive summary of best practices, along with a means of tracking their adoption, can be found both within the Data Center Maturity Model from The Green Grid[16] and within the EU Code of Conduct on Data Centers.[17]

This document is primarily oriented around the delivery of infrastructure (as IaaS), that being the current prime focus of much of the industry and a good starting point for such subjects. But it is entirely feasible for service providers at other levels (for example, SaaS) to identify and report the embedded carbon footprint within their services by extrapolation from what is described herein.

The carbon footprint is not expected to be a 100-percent accurate or deterministic figure. To measure everything can be very expensive, in both financial and environmental terms. Thus, there is likely to be a need for some degree of approximation, which should be indicated.

[16] See http://www.thegreengrid.org/sitecore/content/Global/Content/Tools/DataCenterMaturityModelAssessmentTool.aspx, for which registration may be required.
[17] See http://iet.jrc.ec.europa.eu/energyefficiency/ict-codes-conduct/data-centres-energy-efficiency

ODCA DOCUMENT ALIGNMENT

This section describes the alignment of Carbon Footprint and Energy Efficiency concepts and requirements with other ODCA documents.

Master Usage Models (MUMs)

- **"Compute Infrastructure as a Service Rev. 1.0."** Impact on power usage and measurement of CIaaS components server, storage, network, lifecycle purchase (also power itself) and disposal requirements.
- **"Service Orchestration Rev. 1.0."** For example, workload/elasticity usage management, ability to suspend what is not used, to resume and auto-scale what's needed; usage logging, monitoring, reporting, and compliance; catalog includes carbon parameters.
- **"Commercial Framework Rev. 1.0."** Carbon footprint is one of the considerations in forming a contractual arrangement; power source and usage; CO_2 calculation/auditability, control, waste disposal.

Automation

- **"VM Interoperability in a Hybrid Cloud Environment Rev. 1.2."** Enabler for moving, ease of load and usage management enables optimized infrastructure utilization, which reduces the carbon footprint.
- **"Long-Distance Migration Rev. 1.0."** Enabler for following cheap/clean power; for example, picking a clean data center for data processing, although migrating as such also costs energy.

Common Management and Policy

- **"Software Entitlement Management Framework Rev. 1.0."** Requirement for licenses not to prohibit moving systems around.
- **"Regulatory Framework."** Flexibility of moving and carbon usage measure is one of the considerations in forming a contractual arrangement; adherence to local regulation on sustainability.

Transparency

- **ODCA "Platform as a Service (PAAS) Interoperability Rev. 1.0"** usage model. Scalability and migration become more important for CO_2 reduction perspective; monitoring also on CO_2 usage.
- **ODCA "Software as a Service (SaaS) Interoperability Rev. 1.0"** usage model. Scalability and migration (including interconnectability and portability) become more important for CO_2 reduction perspective; monitoring also on CO_2 usage.
- **ODCA "Interoperability Across Clouds Guide Rev. 1.0."** Scalability and migration (including interconnectability and portability) become more important for CO_2 reduction perspective; monitoring also on CO_2 usage.
- **ODCA "Service Catalog."** Attributes to include CO_2 usage in service entries, along with their price.
- **ODCA "Standard Units of Measure Rev 1.1."** Describe the CO_2 usage values used and align them to other measures used; expand to full lifecycle (power) purchase and waste disposal.

METHODS OF REDUCTION

This section describes how those involved can obtain advice and guidance on reducing their carbon impact.

The possible measures can broadly be categorized in alignment with the PUE number, of "1.n": representing the impact of the IT equipment itself and the compounding impact of housing that equipment.

- The "1:" techniques of development and architecture to reduce the quantities of IT equipment required, including but not limited to virtualization
- The "n": the effects of data center building construction and management

As mentioned in the Usage Requirements section, the size of the carbon footprint within a data center can be managed along two vectors: PUE and energy source. PUE has a further direct tie to business costs of obtaining a cloud service; that is, greater use of electricity equates with higher operating cost and higher subscription cost.

Loosely borrowing from Microsoft[18] work on a "green maturity model for virtualization," the following principles should be seen by cloud subscribers as goals towards reduction of carbon footprint, albeit represented in reverse logical order:

- Select a cloud provider based on its service location and its access to low emission energy, plus high energy usage effectiveness (low PUE value).
- Minimize the use of dedicated hardware and instead aim to maximize sharing of servers and storage, subject to your organizational security policies.
- Consolidate applications to minimize the number of servers required, subject to security and business recovery requirements. If buying SaaS, ask your cloud provider to show how effective it is at this consolidation.
- Design applications for a cloud environment. Develop and test applications for efficiency of code (more efficient code typically uses less compute and storage power). As with application consolidation, ask the cloud provider to show how effective it is at application design for a cloud.
- Minimize the amount of data collected and stored to just what you need to accomplish your mission.

With a nod to The Green Grid and its case study from eBay,[19] the following can serve as further design points to cloud providers to attain greater data center efficiency:

- Optimize individual servers based on their power consumption and ability to vary it (that is, through CPU frequency).
- Place servers for different applications in the appropriate locations to meet the up-time requirements.
- Roll out servers in various levels of granularity such as a rack at a time (including varying rack density), a module, a container, or a new data center.

In their efforts to reduce their carbon footprint, cloud subscribers could also benefit from a marketplace where a "carbon emissions directory" of cloud providers is published. Each provider could list their offerings, which could range from more to less efficient, and those could be matched with candidate subscriber business needs.[20]

There are many possible sources of advice regarding the improvement of the environmental impact of data center operations, including the Greener Data Centers Cookbook[21] from Atos, and documents from T-Systems and Intel published under the Data Center 2020 banner.[22]

Key Perspectives for Cloud Providers on Data Center Operations and Green Data Centers

The carbon impact of data centers can be reduced through several techniques to improve the efficiency and sustainability of data centers. From a principles perspective, the cloud provider can attain this goal through five types of measures.

- Select more-efficient equipment, giving more performance for the power consumed or just using less power; for example, as measured in SPEC/watt
- Use less of that equipment, or use it more efficiently: consolidate and virtualize servers, and so on
- Manage it more efficiently: for example, switch it off when it is not being actively used (from "always on" to "always available")
- House it more efficiently in the data centers, with lower PUE
- Use "greener" electricity, usually done by buying it from reusable sources

Power and cooling are increasingly the major constraints within a modern data center environment; space much less so. Effective management of power and cooling can pay significant dividends.

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[18] http://msdn.microsoft.com/en-us/library/dd393310.aspx

[19] See www.thegreengrid.org/~/media/Case%20Studies/CS3-Breaking_New_Ground_on_Data_Center_Efficiency.pdf?lang=en

[20] See www.cloudbus.org/talks/Energy-EfficientCloudComputing-Feb2012.ppt

[21] "Greener Data Centres Cookbook," Mick Symonds, Atos, published September 2009.

[22] See www.datacenter2020.com

Techniques to Optimize Power Consumption and Support Effective Power Management

Techniques to optimize power consumption and support effective power management include the following:

- Measure and track the PUE of the data center by using installed measuring and metering equipment at all major power distribution points. Set a baseline for understanding cost, and track and manage variances and improvements.
- Have someone knowledgeable "walk the data center rooms" every day to check for anomalies and issues. A process should be in place to handle any issues that arise, as managed incidents.
- Establish a method to determine which, if any, of the installed systems are unused and arrange to switch them off.
- If there is a significant amount of non-critical equipment installed that needs only a single power supply, consider housing it in a special area, where simpler power provision can be made.

Techniques for Cooling

Techniques for cooling include the following:

- Make effective use of the hot and cold aisle techniques. A detailed description can be reviewed in the "Greener Data Centers Cookbook."
- There should be a formal maintenance schedule for all infrastructural items within the data center, especially for items such as air-handling units, the air-cleaning filters of which need periodic replacement.
- The temperature and humidity ranges within a data center need to be considered in combination.[23]

Techniques for Optimizing Data Center Layout

There are a number of ways in which the layout of data center rooms can be optimized for operational efficiency. Some changes to data centers can be done today, in an existing data center and without major disruption or investment. Others may need to wait for a refurbishment or restructuring exercise.

- **Power.** Create a "master plan" for floor layout, dividing the room into (logical) "zones" of around 100 m^2 and managing power and cooling by those; to do that, classify workloads as per the amount of power used per cabinet, so that you have high, medium, or low power areas.
- **Cooling.** It really matters that cooling is providing enough of the right air (currently $< 27°C$, 30 <rh> 55%, determined by the ASHRAE guidelines) to the air intake (usually the front) of the equipment; the rest is determined by how the hardware vendors manage cooling within their systems.
- **Equipment.** If there is a particular set of equipment that has a much higher heat density than the rest, it may be worth putting it in one specific area and adopting extra techniques to cool that particular area: enclosing the aisles or using in-row or in-rack cooling techniques.
- **Static pressure and airflow.** Managing the static pressure and the airflow within the room layout is important. Computer Fluid Dynamics (CFD) software can be used to model the data center layout and the effect of making any changes.

Designing New Data Centers

There are a number of ways in which data centers can be designed and deployed for more efficient and environmentally acceptable operation, but they may involve considerable design work and investments.

- One option, applicable for some purposes, is to locate the data center in a cooler location: further north (in the northern hemisphere) and/or at a higher elevation. This may prevent having to cool lots of air or water, as the environment is naturally cooler. However, the level of humidity must be balanced against the cold.
- Uninterruptible Power Supplies (UPSs) represent a significant overhead within data center infrastructures. The traditional manner of engineering them is to use a bank of batteries, which also involves a conversion of incoming power from AC to DC for storage, and then back to AC. Just keeping the batteries charged is a significant overhead, as are the power conversions. Avoid putting all of the power used through the UPS mechanism. Instead, in normal operations, only the "delta" required to smooth the power source goes through the UPS.
- In relation to cooling, one recognized method of improving efficiency is air-side economizing, one form of which is to use naturally cool air from outside within the data center, instead of cooling it using complex and expensive cooling techniques. This means bypassing the air cooling system when the outside air is of low-enough temperature, which is the case in most locations most of the time.

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[23] See various recommendations in documents from ASHRAE (www.ashrae.org/)

- The cooling system can be extended by the use of thermal storage tanks, which can be charged up when it is cooler (for example, at night, in the winter), and then provide a means to "ride through" warmer periods (for example, summer afternoons).
- One option that has emerged is the possibility of combining data centers with greenhouses, which themselves need quantities of heat and power for the lamps. A combined heat and power (CHP) generation plant is shared between them, and the excess heat from the data center is used in the greenhouses. During the summer, excess heat is stored in the ground for use during the winter. This does require the geographical circumstances of a suitable location, which are limited, for both types of businesses.

Energy Sourcing Options and Location of Cloud Services

There are a number of ways in which "greener" and possibly cheaper electrical power can be obtained, the applicability of which depends very much on cloud subscriber and cloud provider's location and circumstances.

It should be noted that there are man-made barriers to achieving optimal power efficiency including:

- **Power generation options.** This may be influenced by government regulation (for example, bans on nuclear power) or geographic location (for example, climate or limited rainfall preventing hydropower) that can significantly impact the efficiency and CO_2 footprint of the power source.
- **Distance from power source.** Significant power is lost in transmission (up to 1/3 per 150 km - depending on age and quality of transmission cabling). Data centers that are located large distances from the source of power generation will have an inherently larger generation footprint than ones located close to the power source.
- **Geographic location.** Government regulation (most prevalent in the finance, medical, and defense industries) may mandate that data must be stored within the jurisdictional area of that government, preventing flexibility in selecting cloud service providers across diverse locations.

The cloud subscriber should consider these factors when selecting a cloud service provider. By locating the cloud services close to an efficient power source, the cloud subscriber could reduce the CO_2 footprint (potentially significantly) required to produce the power needed for cloud services.

Data Center User Behavior

- Once purchased, equipment should be configured and used as efficiently as possible. This can influence decisions regarding how high availability and disaster recovery are to be provided: having an extra full set of equipment on standby may be far less efficient than some form of load balancing. At the system level, virtualization limits the amount of under-used kits because it allows multiple logical systems to be run on one physical system.
- Choose systems from hardware vendors that deliver more processing power or use less electricity, as measured, for example, by SPEC/watt.
- Mainframes have always had a role to play for those who require their level of reliability, but are now also being recognized as a very efficient form of processing because of their relatively low power consumption.
- Power supplies within servers are a major point worthy of attention. In a worst case, they can use and thus waste as much power as does the processor itself. Customers should be persuaded to invest in systems that use more efficient power supplies, with a target of increasing efficiency from 80% > 85% > 90+%.[24]
- For storage systems, techniques such as de-duplication and thin provisioning can reduce the amount of real storage capacity that is required. For that real storage, the big development in energy savings is the use of systems that are idle when not in active use: a MAID (Massive Arrays of Idle Disks). These are disks that are actually designed to spin down when not being accessed, without impacting their availability or reliability, and only minimally elongating access times.

[24] See information on "80-plus" power supplies from the Energy Star organization, at www.energystar.gov

PROOF OF CONCEPT

Atos

As a major global IT services provider, Atos runs a large number of data centers, housing both traditional and cloud computing environments. These are equipped with toolsets to monitor and manage the IT equipment housed as well as the data centers themselves. However, in recent months an exercise has been taken, in conjunction with Siemens as a partner, to join the IT and infrastructure management environments together, using a methodology known as Data Center Infrastructure Management (DCIM).

The full integration suite has already been implemented as a proof of concept within one of Atos' Cloud Hub data centers and allows overall monitoring, management, and reporting of the overall carbon footprint to be done. It is now proposed to extend this with the methods embodied within this document, to allow the carbon footprint[25] to be analyzed and reported down to the individual user and workload level.

Collaboration between Intel and T-Systems: Data Center 2020 Project

The Data Center 2020 project focuses on energy optimization at existing data centers.[26]

The Data Center 2020 is a joint T-Systems and Intel data center test laboratory in the Munich-based Euroindustriepark. The two companies are working to determine methods by which energy efficiency and operations in existing data centers can be optimized. Based on this work and the knowledge derived, the team is also developing a model of the data center of the future. So far, the researchers have demonstrated improved energy efficiency through the consistent separation of cold and hot air and by raising the supply air temperature and provisioning to a higher energy density in the rack. A substantial proportion of the lower energy consumption is due to being able to optimize the airflow rate through variable speed fans in the cooling units, a capability derived from the cold-aisle containment. In this, the third phase of research, the team has repeated the efforts outlined in the first two white papers, with a hot-aisle containment to compare and contrast it with the improvements found with the cold aisle containment.

In the first phase of the optimization the researchers from T-Systems and Intel reduced data center energy consumption by two simple means:

- **With the upper limit of the ASHRAE recommendations to provide a computer inlet temperature (TA) of 27°C.** The strict separation of cold and hot air in the raised floor and the cold aisle containment lead to optimized air ducting and minimization of leakage and airflow mixing. This can also reduce the fan speed of the circulating air cooling units.
- **Raising the supply air temperature delivered under the raised floor (T1) along with a coincident increase of the chilled water temperature.** This minimizes the hours required for cooling by the chillers and extends the hours available for indirect free cooling. The PUE result could be further improved if the cooling air temperature was increased in accordance.

With these initial measures, the researchers succeeded in reducing the DataCenter 2020 PUE ratio from 1.8 to 1.4, with the computer inlet temperature remaining unchanged at 22°C.

T-Systems and Intel will implement the initial findings from research conducted at DataCenter 2020 into their own projects for the optimization of data centers. In the next step of the project, the experts will examine to what extent the data center infrastructure can be controlled by the IT load so that energy consumption is also optimized in the partial-load operational range. The long-term objective is "infrastructure on demand," whereby the infrastructure in the data center supplies the servers with the exact amount of cooling output that they need at this moment in time.

Several white papers and results have been published, which can be accessed through www.datacenter2020.com

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[25] Atos has certification from its supplier that all the power in the relevant data centers comes from "green" sources—in this case primarily an off-shore wind farm. However Atos also contributes to an offset scheme, planting trees in India. It will be interesting, in the calculations, to work out how to accommodate these "belt and braces." www.atos.net

[26] www.datacenter2020.com

RFP REQUIREMENTS

The request-for-proposal (RFP) process allows the cloud subscriber to compare and select between cloud providers based on their carbon footprint.

The Alliance recommends the inclusion of the following requirements in RFPs to cloud providers so that proposed solutions can calculate and report the carbon footprint of services provided from the cloud:

- **ODCA Principle Requirement.** Solution is open, works on multiple virtual and non-virtual infrastructure platforms, and is standards-based. Describe how the solution meets this principle and any limitations towards the ODCA principle.
- **ODCA Carbon Footprint and Energy Efficiency Usage Model 2.0.**
  - Solution follows a known standard (as per this ODCA Carbon Footprint Usage document) to calculate CO_2 emissions; approximations and degrees of variance are stated where applicable.
  - Solution should show the source or sources of CO_2 emission (where is the power being delivered from, such as hydroelectric power, coal, or nuclear power).
  - Solution may also show carbon offsets, if applicable solution is able to monitor the carbon consumption by equipment and by cloud subscriber and to chart the history of usage over a given time interval.
  - Solution should be able to control the carbon utilization by being able to move a workload to different (cleaner and/or more efficient) equipment or another location.
  - Solution should include the embedded carbon amortization separately itemized. If this information is not available, this fact should be highlighted.
  - Solution should include confirmation of the EDE (equipment disposal) being implemented. If this information is not available, this fact should be highlighted.
  - Billing reports are to show carbon footprint for the billing period.

The ODCA provides the Proposal Engine Assistant Tool (PEAT) which is an online tool to help you detail your RFP requirements: www.opendatacenteralliance.org/ourwork/proposalengineassistant

SUMMARY OF INDUSTRY ACTIONS

For guidance on how to create and deploy solutions that are open, multi-vendor, and interoperable, we have identified specific areas where the ODCA suggests there should be open specifications, formal or de facto standards, or common intellectual property-free (IP-free) implementations. The specific areas in this usage model where we suggest that these specifications, standards, and open implementations be developed are flagged with an asterisk (*) in Table 2. Where the ODCA has a specific recommendation on the specification, standard, or open implementation, it is noted in this usage model. In other cases, we will be working with the industry to evaluate and recommend specifications in future releases of this document.

Table 2 lists the industry actions that are required to refine this usage model.

Actor	Recommended Industry Action
Cloud Service Provider	• Identify the applicable carbon footprint metrics for relevant service components, and integrate the decision making information within service catalogs, reporting, billing, and monitoring processes to support a transparent and per-tenant view of carbon footprint and emission • Provide feedback from usage experiences to the ODCA
Cloud Standards Body	• Drive the development and standardization of common information models to profile the key attributes associated with carbon emission computation and reporting, such as power profiling and CPU profiling • Recommend standard interfaces to support the implementation and use of information models across different cloud service providers • Develop standard service guidelines and methods for the following: – Service order workflow – Service configuration associated with Power Usage Effectiveness (PUE) – PUE calculation engine with location reporting – Carbon-aware service scheduler – Performance and power measurement per virtual machine – Node thermal sensors, power monitoring, and power consumption
ODCA	• Agree on a recommended default methodology for carbon footprint measurement (possibly in conjunction with The Green Grid)* • Propose a standard method and unit for representation of the metrics within ODCA Standard Units of Measure (SUoM) deliverable and integrate the required units of measure within the ODCA Service Catalog deliverable
Cloud Subscriber	• Apply the ODCA Carbon Footprint and Energy Efficiency usage model, continually review usage and experiences in practice, and provide real-life feedback to the ODCA • Benchmark the carbon footprint measures on a periodic basis, to ensure reliability (potentially with the assistance of third parties)*