

Harmonizing Global Metrics for Data Center Energy Efficiency

Global Taskforce Reaches Agreement Regarding Data Center Productivity

March 13, 2014

The data center has become an increasingly important part of most business operations in the twenty-first century. With escalating demand and rising energy prices, it is essential for the owners and operators of these mission-critical facilities to assess and improve data center performance using energy efficiency and greenhouse gas (GHG) emission metrics. However, even with the global presence of many companies, these metrics often are not applied consistently at a global level.

To address these inconsistencies, a group of global leaders has been meeting regularly to agree on standard approaches and reporting conventions for key energy efficiency and GHG emission metrics. These organizations are: the U.S. Department of Energy's Save Energy Now and Federal Energy Management Programs (March 2009 – October 2012); the U.S. Environmental Protection Agency's ENERGY STAR Program; the European Commission Joint Research Centre Data Centres Code of Conduct; Japan's Ministry of Economy, Trade and Industry; Japan's Green IT Promotion Council; and The Green Grid Association.

In February 2011, the Taskforce released a joint statement that highlighted the agreement reached specific to measurement protocols for the power usage effectiveness metric (PUE). The 2011 statement also included further goals and guiding principles for collaboration. In October 2012, the Taskforce released another joint statement providing measurement guidelines for three additional metrics: green energy coefficient (GEC), energy reuse factor (ERF), and carbon usage effectiveness (CUE).

This current document, the last joint statement from the Taskforce, reflects agreements reached as of March 6, 2014. It provides recommendations for quantifying data center energy productivity and an update regarding data center productivity proxies, thus fulfilling this Taskforce's current objectives.

Goal

Share global lessons and practices with an objective of arriving at a set of metrics, indices, and measurement protocols that can be formally endorsed or adopted by each participant organization to improve data center energy efficiency and GHG emissions globally. This objective includes the following specific goals:

1. Identify an initial set of metrics.
2. Define each metric.
3. Define the process for measurement of each metric.
4. Establish an ongoing dialog for the development of additional metrics.

Desired Outcomes

The Taskforce has identified several desired outcomes for its activities.

Outcome (1) – Effective energy efficiency metrics that measure the actual IT work output of the data center compared to its actual energy consumption. It is of note that in the process of defining IT work output, the following interim measurements are being defined and/or validated:

Outcome (1.a) – IT – Measure the potential IT work output compared to expected energy consumption, and measure the operational utilization of IT equipment.

Outcome (1.b) – Data center facility and infrastructure – Measure the data center infrastructure and efficiency (i.e., power usage effectiveness or PUE).

Outcome (2) – Measure renewable energy technologies and reuse of energy to reduce carbon.

Guiding Principles

The Task Force recommends that the various data center efficiency metrics developed to address Outcomes (1.a), (1.b), and (2) be viewed in a holistic, multi-parameter framework, such as a spider chart, to help understand interactions among them. Viewing the metrics in a multi-parameter framework helps owners and operators identify the effects of changes made to the data center specific to the various efficiency metrics. (See Appendix F – Holistic Framework for more details on this approach.) Along with the energy efficiency and GHG emission measurements and metrics, data center owners and operators should keep absolute values in the forefront of all decision making. Attempting energy efficiency or GHG emission programs should help to decrease the absolute energy use or GHG emissions per unit.

The Taskforce has finalized discussions and agreed on the following:

Outcome (1) – It is recommended that data centers begin to define attributes and measure data center energy productivity (DCeP) according to the following:

- DCeP is an equation that quantifies useful work that a data center produces based on the amount of energy it consumes. DCeP is computed as useful work produced divided by total energy consumed by the data center. DCeP allows each user to define useful work as applicable to the user's business. This aspect allows each user to create a custom metric that is meaningful for each user's environment. Inconsistencies in data center comparisons can develop with this approach, but the intent is that over time, through use of the metrics and communication, the industry can harmonize the attributes to minimize inconsistency in comparisons. DCeP is discussed in greater detail in Appendix G – Data Center Energy Productivity (DCeP)

Outcome (1.a) – This Taskforce has always aimed to recommend specific and comprehensive metrics to address each outcome. In the case of Outcome (1.a), the Taskforce did not reach consensus for a recommendation. However, the Taskforce has studied a wide range of proxies for data center productivity and has narrowed the field to three proxies that each addresses this outcome in a different way. Appendix H lists the proxies studied and describes the approach and process employed by the Taskforce.

Outcome (1.b) – It is recommended that data centers begin to measure PUE according to these principles:

- PUE using source energy is the preferred energy efficiency metric. PUE is a measurement of the total energy of the data center divided by the IT energy consumption.
- The industry should improve IT measurement capabilities to ultimately enable taking the measurement directly at the IT load (e.g., servers, storage, networking, etc.). The recommendation is to measure the IT energy at the output of the power distribution unit (PDU). At a minimum, IT energy measurements should be measured at the output of the uninterruptible power supply (UPS).
- For a data center, total energy measurement should include all energy sources at the point of utility handoff. Total energy should include all cooling, lighting, and support infrastructure, in addition to IT load.
- Additional details on measurement guidelines have been added in Appendix A – Power Usage Effectiveness (PUE) Measurement Details for PUE measurements, including guidelines specific to equitable measurements of PUE with various designs: using multiple energy inputs (including renewable energy), on-site generation, and reuse of energy.

Outcome (2) – It is recommended that data centers begin to measure GEC, ERF, and CUE according to these principles:

- GEC is a metric that quantifies the portion of a facility’s energy that comes from green sources. GEC is computed as the green energy consumed by the data center (measured in kilowatt-hours or kWh) divided by the total energy consumed by the data center (kWh). For the purposes of GEC, “green energy” is defined as any form of renewable energy for which the data center owns the rights to the green energy certificate or renewable energy certificate, as defined by a local/regional authority. This definition is discussed in greater detail in Appendix C – Green Energy Coefficient (GEC) Measurement Details. The “total energy consumed by the data center” is the total source energy, calculated identically to the numerator of PUE.
- ERF is a metric that identifies the portion of energy that is exported for reuse outside of the data center. ERF is computed as reuse energy divided by the total energy consumed by the data center. Reuse energy is measured as it exits the data center control volume. (For more, see Appendix D – Energy Reuse Factor (ERF) Measurement Details.) The “total energy consumed by the data center” is the total source energy, calculated identically to the numerator of PUE.
- CUE is a metric that enables an assessment of the total GHG emissions of a data center, relative to its IT energy consumption. CUE is computed as the total carbon dioxide emission equivalents (CO₂eq) from the energy consumption of the facility divided by the total IT energy consumption; for data centers with electricity as the only energy source, this is mathematically equivalent to multiplying the PUE by the data center’s carbon

emission factor (CEF). These calculation approaches are further defined in Appendix E – Carbon Usage Effectiveness (CUE) Measurement Details.

This guidance is meant to drive a common understanding of energy efficiency metrics. The Taskforce has met in the U.S., Italy, and Japan and recently celebrated five years of collaboration. With the release of this memo, the Task Force concludes its fulfillment of current desired objectives.

Participating Organizations

Each of the following organizations is represented on the Taskforce, which convened regularly to advance the group's progress.

For further details, please contact:

- U.S. Department of Energy Save Energy Now Program (March 2009 – October 2012): <http://www1.eere.energy.gov/industry/datacenters/contacts.html>
- U.S. Environmental Protection Agency's ENERGY STAR Program: www.energystar.gov/datacenters
- European Commission – Joint Research Centre, Data Centres Code of Conduct: <http://iet.jrc.ec.europa.eu/energyefficiency/ict-codes-conduct/data-centres-energy-efficiency>
- Japan's Ministry of Economy, Trade and Industry: <http://www.meti.go.jp/english/index.html>
- Japan's Green IT Promotion Council: <http://www.greenit-pc.jp>
- The Green Grid Association: gdcmetrics@lists.thegreengrid.org

List of Appendices

Appendix A – Power Usage Effectiveness (PUE) Measurement Details 6

Appendix B – Power Usage Effectiveness (PUE) Illustrative Calculation Examples 10

Appendix C – Green Energy Coefficient (GEC) Measurement Details 13

Appendix D – Energy Reuse Factor (ERF) Measurement Details..... 17

Appendix E – Carbon Usage Effectiveness (CUE) Measurement Details..... 19

Appendix F – Holistic Framework..... 24

Appendix G – Data Center Energy Productivity (DCeP) 27

Appendix H – Data Center Productivity Proxies 28

Appendix A – Power Usage Effectiveness (PUE) Measurement Details

The seemingly simple concept of PUE requires additional detail to ensure that it is applied consistently across data centers. Consistent calculations of PUE facilitate communication of performance among data center owners and operators.

PUE is computed as follows:

$$PUE = \frac{\text{Total Data Center Source Energy}}{\text{IT Source Energy}}$$

The following clarifications apply to the PUE calculation:

- **Total Energy (Data Center Boundary)** – Total Energy should be measured at the point of utility hand off to the data center. This may include measurements of electricity, chilled water, natural gas, fuel oil, or other purchases made from a utility. All measurements should be made from the point where the energy is purchased. In the case where natural gas is purchased to produce chilled water or electricity, measurement shall occur of the natural gas purchase and *not* of the secondary energy it produces. Electricity from renewable energy sources should be included in the total energy and assigned the same source factor as grid electricity.
 - **Consistent Units** – All energy shall be reported using the same units, and the recommended unit of measure shall be kWh. Standard thermal conversion factors shall be used to convert to kWh (e.g. 1 kWh = 3.412 kBtu; 1 GJ = 278 kWh).
- **IT Energy** – IT Energy shall be measured in kWh. The recommendation is to measure the IT energy at the output of the PDU. At a minimum IT Energy should be measured at the output of the UPS.
- **Source Energy** – Source Energy is a means of assessing the total primary energy use or fuel consumption at a data center. The purpose of source energy is to ensure that data centers that purchase different forms of energy (electricity, natural gas, chilled water) can compare their total consumption equitably. For example, if one data center purchases chilled water from a local utility company while another data center uses electricity to produce chilled water onsite, a factor is required to put the two utility bills in common units for comparison. This factor is called a source energy factor, and it is a factor to reflect the total fuel consumption.

Because the majority of data centers operate with 100% electricity, this global group recommends source energy factors that are weighted with respect to electricity. In other words, after source factors are developed for each fuel, they are each expressed relative to the source factor for electricity. This convention allows for any electric purchases to be multiplied by a factor of one. Purchases of other fuels are multiplied by their respective factors before being added to the total.

*Weighted energy for each energy type = (Annual energy use * source energy weighting factor)*

The source energy factor is inherently a regional factor because the amount of fuel needed to produce one unit of electricity (or chilled water) will depend on the predominant method of electric (or chilled water) generation in the specific country. Some countries have published values for these conversion factors (such as the EPA ENERGY STAR Program). However, to enable a fair global comparison, this global group recommends that standard, global factors be applied. Global factors represent average values of factors from different regions. While the global factors are recommended for comparisons across different regions of the world, regional factors may be applied for greater accuracy of comparison within a specific region.

The global average source energy weighting factors shall be:

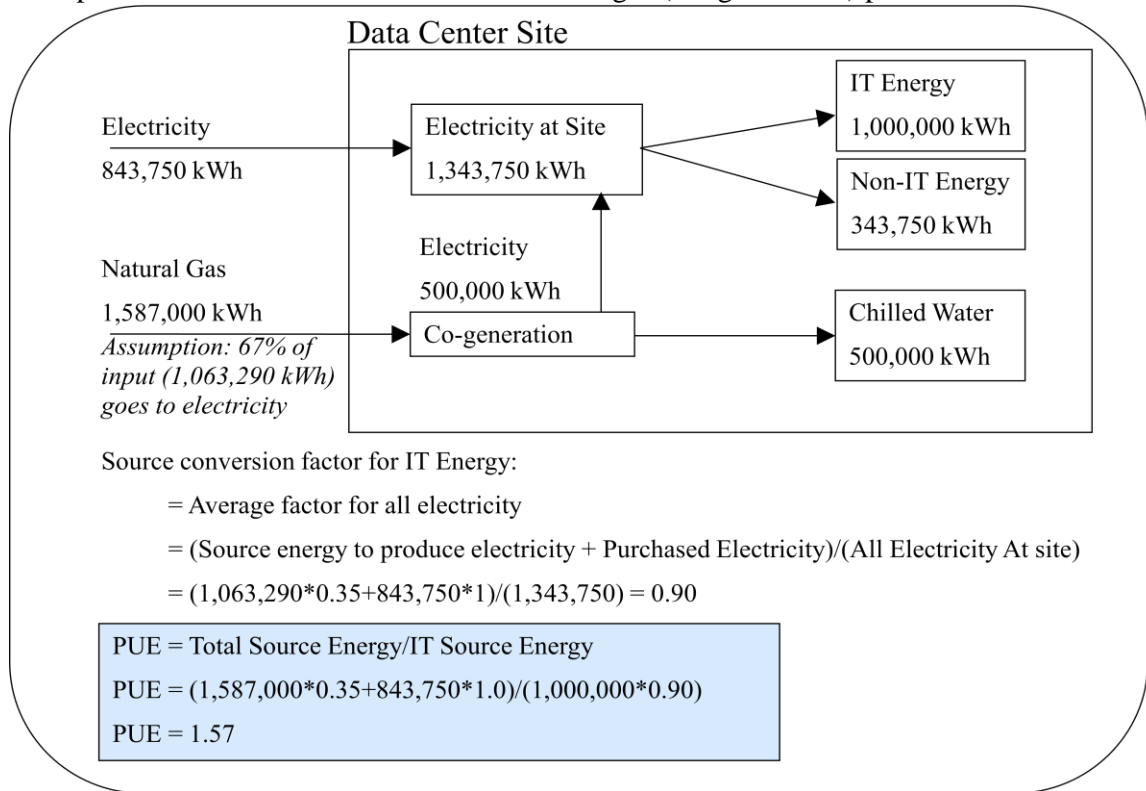
<i>Energy Type</i>	<i>Weighting Factor</i>
Electricity	1.0
Natural gas	0.35
Fuel oil	0.35
Other fuels	0.35
District chilled water	0.4
District hot water	0.4
District steam	0.4

Table 1: Global average source energy weighting factors

To express Total Source Energy, each fuel should first be converted into a single common unit (kWh); then each fuel should be multiplied by its weighting factor; finally, the source energy for all fuels can be summed together.

- On-Site Electric Generation – To enable equitable PUE calculations in data center designs that operate on-site electric generation two topics need to be explained:
 - IT Source Energy Conversion Factor
 - To ensure the PUE calculations for a design including on-site electric generation and a design excluding on-site electric generation are equitable, the taskforce has introduced the IT Source Energy Factor. The IT Source Energy Factor enables the data center owner / operator to include the efficiencies of generating chilled water (as in all calculations for PUE), but exclude the efficiencies of generating electricity (as in all calculations for PUE). PUE is not a metric to identify the efficiencies of how electricity is brought to the data center, it is a metric to identify how efficient the electricity is used from the data center control volume to the IT Equipment.

- Example A: Data center with electric and natural gas (Co-generation) purchase



- Cogeneration Input Fuel Assumption

- This taskforce has adopted the assumption that 67% of a cogeneration plants' input fuel is allocated to the primary form of generation (electricity in the provided example) and respectively 33% of the primary input fuel is allocated to the secondary form of generation (chilled water in the provided example).
- This assumption is based on a similar steam based cogeneration study from the U.S. Environmental Protection Agency's Energy Star Program. Differences do exist between the two scenarios, but to solidify the methodology of calculating PUE and to drive consistent and equitable calculations for all design types, this taskforce is proceeding with the recommendation to adopt this approach. As further data specific to cogeneration examples are provided, the data will be taken into consideration. Provided there is a material change in calculations, the taskforce will consider updating the recommendations specific to this assumption.
- Stakeholder feedback is welcome and encouraged to continue the adoption, consistent communication, and equitable calculations for PUE in an effort to improve energy efficiency.

- Energy Re-use – Energy that is re-used shall *not* be subtracted from the total energy use of the data center.

- If the energy is reused within the datacenter, the value of the reused energy will already be contained within the PUE calculation and needs no special consideration. An example will be reusing waste heat to warm a battery space in a cool climate. The PUE would generally be lower because the HVAC system does not have to add as

much energy to heat that battery space, thereby reducing the PUE when energy is measured and PUE calculated.

- If the energy is reused outside the data center (e.g. re-using heat to warm a lab that is not part of the data center), the PUE of the data center is not affected. While the effort to conserve energy is laudable, it cannot be accounted for in the calculation of the data center PUE because it does not lower the actual total energy need of the data center.

- Measuring PUE in a Mixed-use Building

- The definition of a Mixed-use Building is a facility that has a data center and services not associated with the data center. As an example a Sales team or Marketing team are also housed within a building, but have no direct support responsibilities for the data center.
- The method for calculating PUE in a mixed use building is the same method for calculating PUE in a dedicated data center except for some ancillary energy loads that can be excluded*:

- Energy required for shared support spaces: (ancillary energy loads)
 - Shared offices
 - Shared labs
 - Shared cubicles
 - Shared conference rooms
 - Shared elevators
 - Shared lobbies
 - Shared Kitchens / break rooms

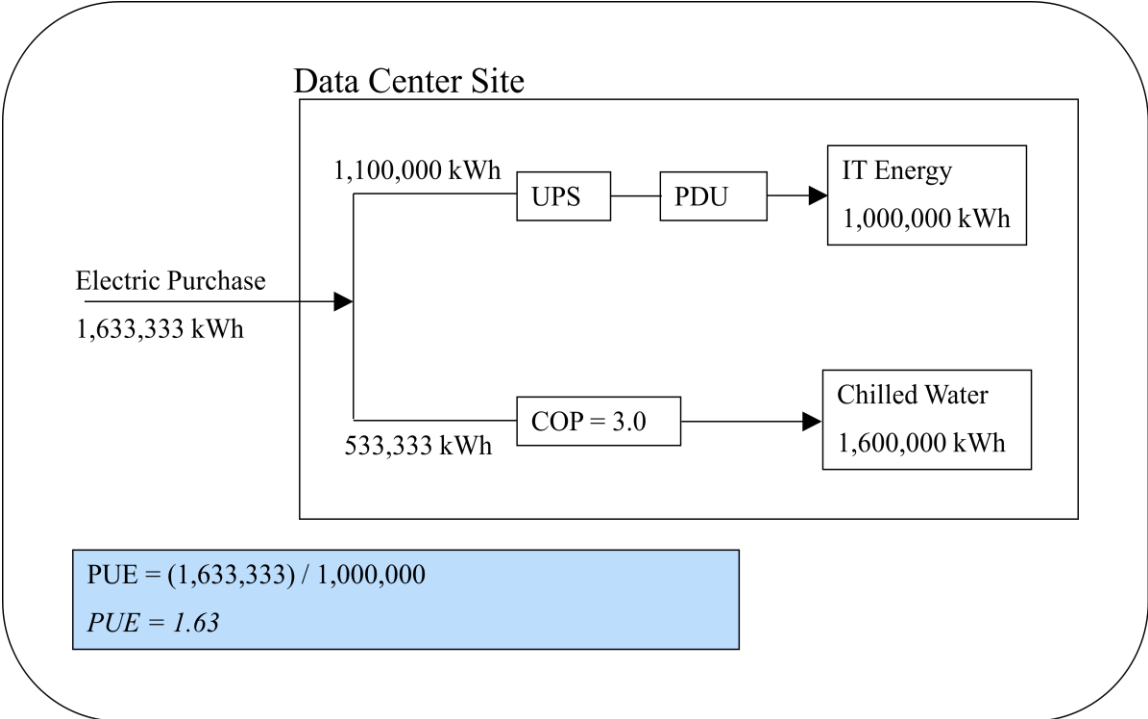
* When excluding any ancillary energy loads this should be declared when reporting PUE.

- The shared elevator is one example to illustrate the rationale for the above noted exceptions. A data center can be a small portion of one floor located on one level of a multistory building. The data center is located on the 5th floor of a 10 story building. The 5th floor also is also mixed-use with many business services and a data center. The effort to implement energy measurements on the shared elevator and the effort to try to quantify how much of that energy should be allocated to the data center traffic on the 5th floor is believed to be a point of diminishing returns. The proportional load for the elevator is insignificant in the PUE calculation.
- Energy consumption of all dedicated space is to be included. As an example if there are offices or cubicles that are dedicated to the data center operations, the energy consumption should be included. Provided the above direction is followed, PUE reporting of data centers within mixed-use buildings follow the same nomenclature as PUE reporting of dedicated data centers.

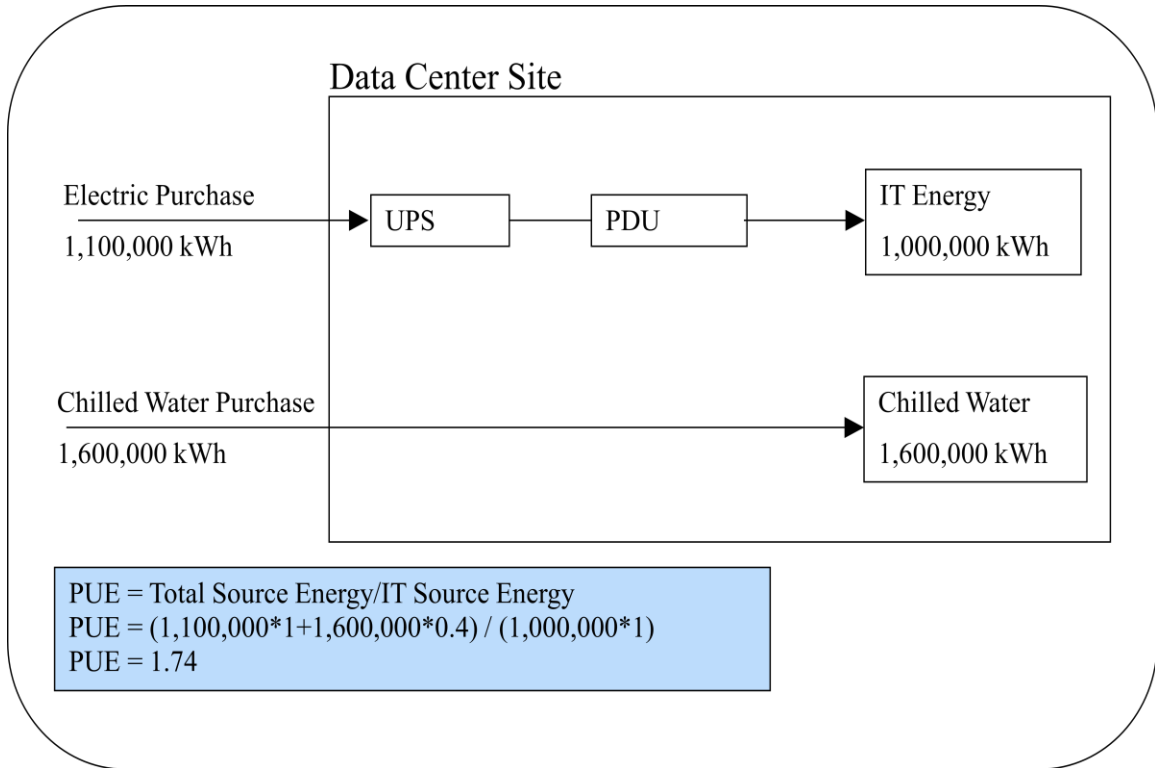
Appendix B – Power Usage Effectiveness (PUE) Illustrative Calculation Examples

The following illustrative examples have been provided to demonstrate a few data center designs and the corresponding approach to calculate PUE by the above recommendations:

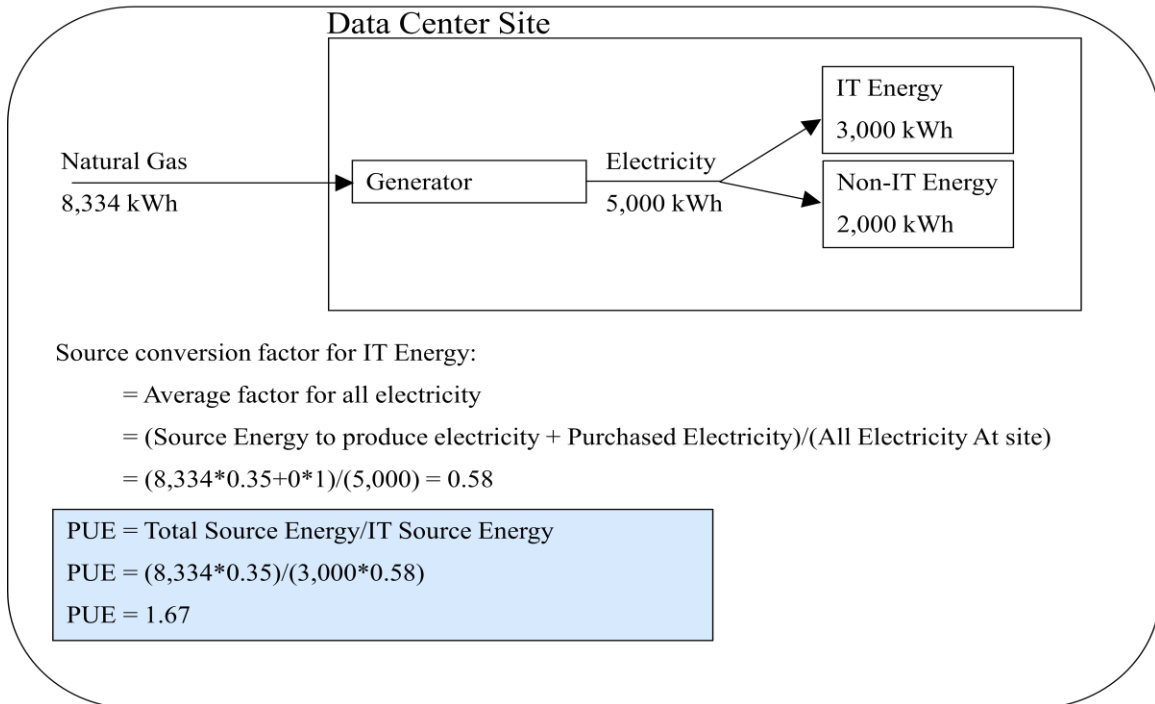
- Example B – Data center with all electric purchase



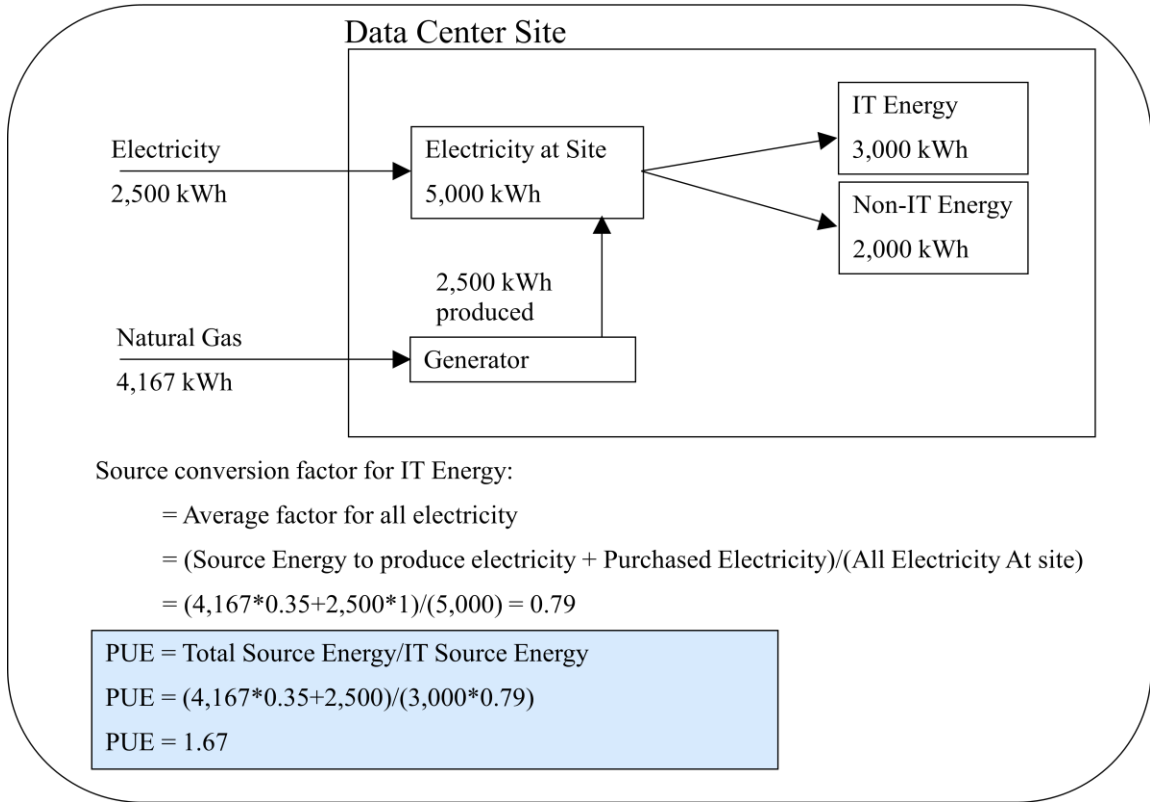
- Example C – Data center with electric and chilled water purchase



- Example D – Data center with natural gas purchase



- Example E – Data center with electric and natural gas purchase



Appendix C – Green Energy Coefficient (GEC) Measurement Details

Conceptually, GEC is a simple metric: the percent of energy that is green.

Complexity arises because there are regional and local differences in the definition of renewable / green energy. These regional differences may occur due to the different types of renewable energy that are prevalent, and due to the market for green energy products in each country. This task force does not attempt to reconcile regional differences.

Rather, this task force recognizes green energy as *any* energy for which the data center owns the legal right to the environmental attributes of green/renewable generation. These legal rights are regionally recognized as Green Energy Certificates, Renewable Energy Certificates, and other similar products. Due to regional differences, this Taskforce recommends all public reporting of GEC include the source issuer of the certificates. Any energy for which the data center owns these rights is considered green for the purposes of this metric. This would include retired Green Energy Certificates, which are no longer a commodity to be traded and are possessions of the last owner or the green certificate system administrator.

The following table contains a number of authorities recognized by this Task Force as defining or issuing the equivalent of a Green Energy Certificate as described herein. This list is not comprehensive and as other regional bodies emerge that issue and track green certificates, that energy should also be counted as green for the purposes of this metric.

<i>Region</i>	<i>Regional Authority / Issuer(s)</i>	<i>Link</i>
E.U.	Association of Issuing Bodies Department of Energy and Climate Change	http://www.aib-net.org/portal/page/portal/AIB_HOME/EECS/Fact_Sheets (See Fact Sheet 4) http://www.decc.gov.uk/en/content/cms/meeting_energy/renewable_ener/renew_obs/renew_obs.aspx
Japan	The Green Energy Certification Center	http://eneken.iej.or.jp/greenpower/eng/index.htm
U.S.A	U.S. EPA Green Power Partnership Green-e	http://www.epa.gov/greenpower http://www.green-e.org/

Table 2: Authorities defining or issuing the equivalent of a Green Energy Certificate

Given this definition of green energy, GEC is computed as follows:

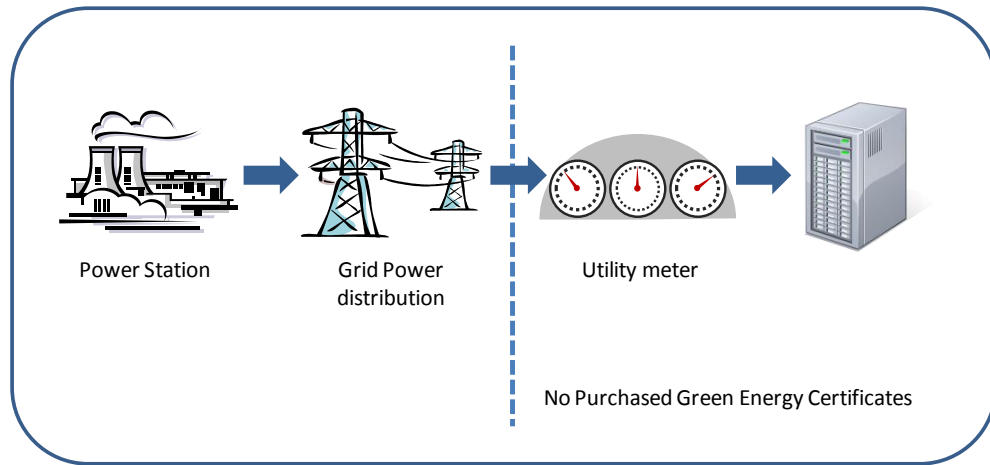
$$GEC = \frac{\text{Green energy used by the data center}}{\text{Total Data Center Source Energy}}$$

GEC has a maximum value of 1.0, indicating 100% of the total energy used by the data center is green energy as defined above. Note that for the purposes of this calculation, the total source energy

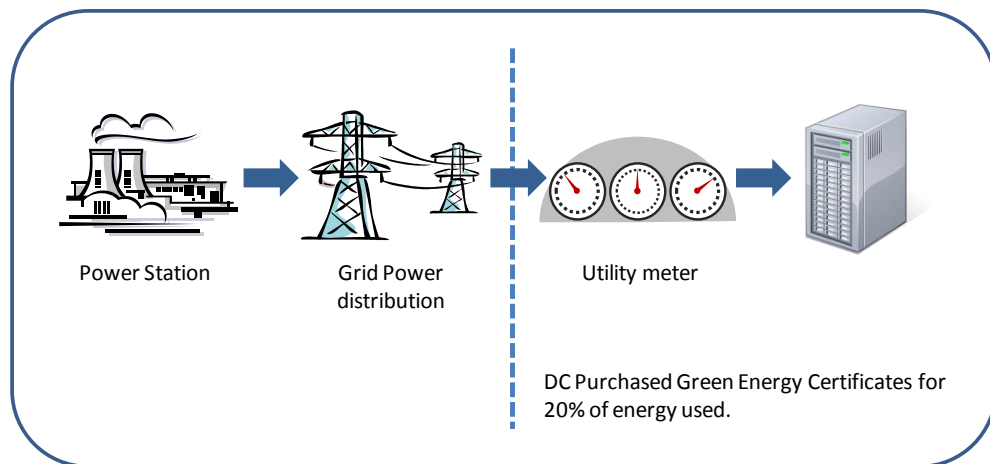
consumed at the data center is identical to the numerator of PUE. As with PUE, all energy shall be reported using the same units, and the recommended unit of measure shall be kWh. Standard thermal conversion factors shall be used to convert to kWh (e.g. 1 kWh = 3.412 kBtu; 1 GJ = 278 kWh). Finally, because the definition of green energy is based on legal ownership of the rights to the environmental benefits it is important to clarify that the location of energy source does not change the calculation of the GEC. For example, a data center may have a solar panel on its roof to generate power; if it sells the Green Energy Certificates associated with this power, then it cannot claim any of that electricity as green. Conversely, a data center that receives electricity entirely from a coal-fired plant may purchase Green Energy Certificates to off-set the entire electric use. These certificates would count as Green Energy.

These concepts are illustrated in several examples, as follows.

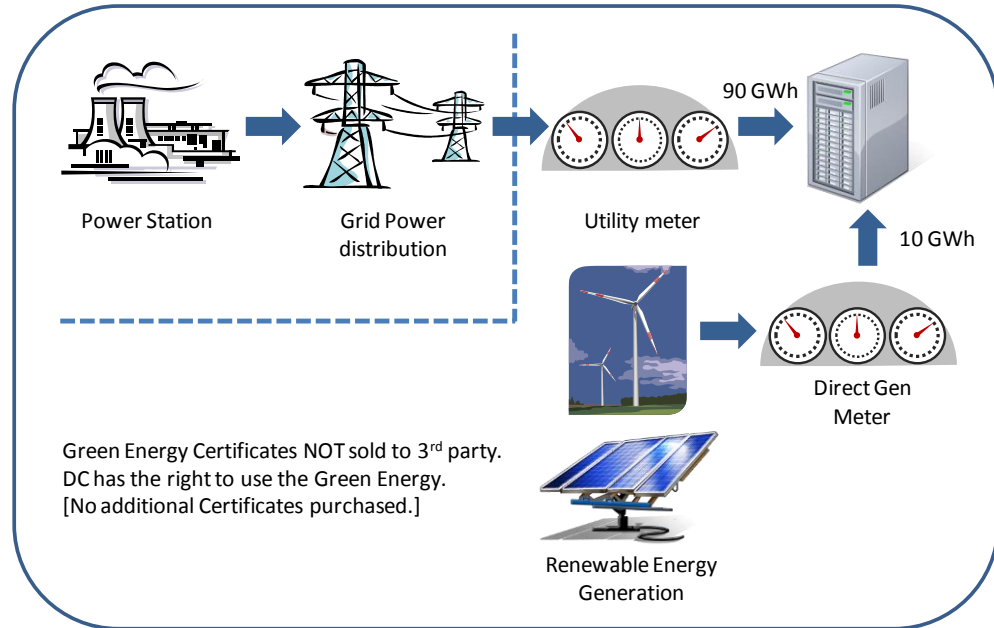
- Example F: Grid energy purchased without Green Energy Certificates: $GEC = 0.00$.



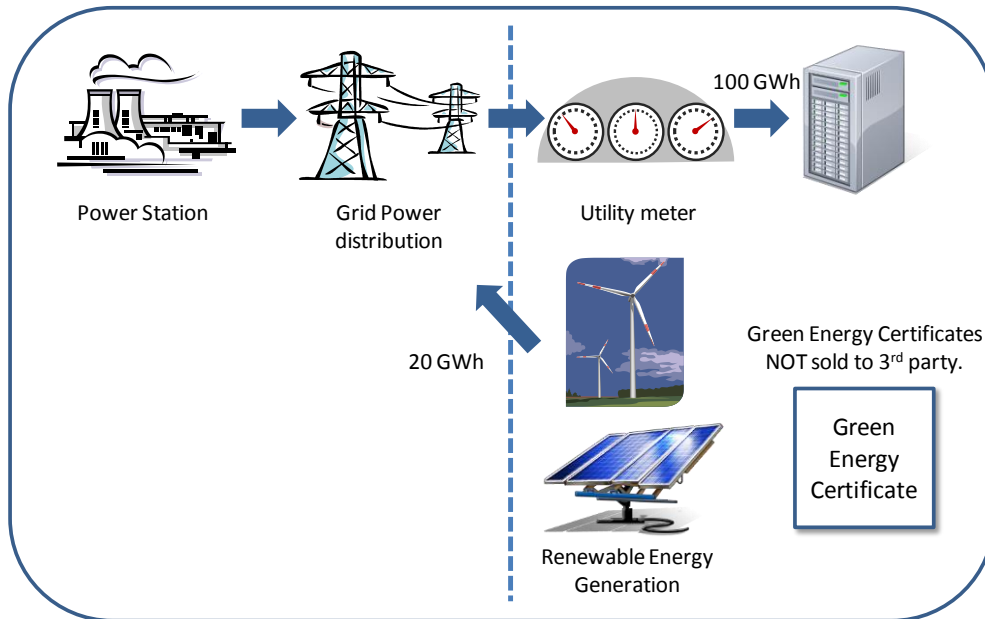
- Example G: Green Energy Certificates purchased and retired for 20% of the energy used by the DC: $GEC = 0.20$



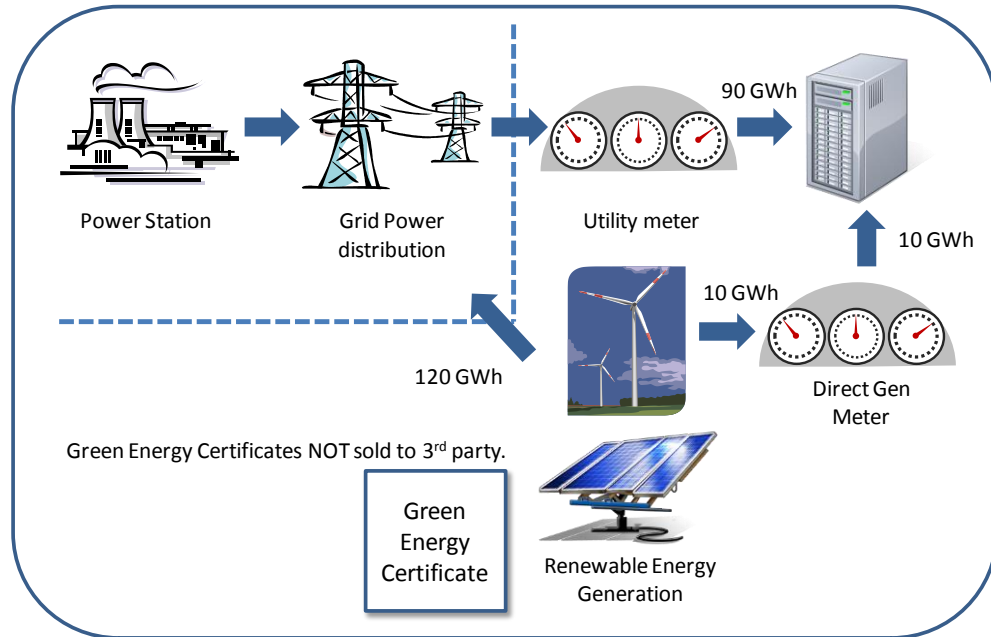
- Example H: Green Energy Certificates for locally generated green energy are retired by the DC: GEC = 0.10.



- Example I: Locally generated energy sold to the utility, but Green Energy Certificates retired by the DC: GEC = 0.20.



- Example J: The DC can retire Green Energy Certificates only for the energy it uses: $GEC = 1.00$. Note that of the 130 GWh generated by renewable sources, the data center could sell 30 GWh worth of Green Energy Certificates without impacting its GEC of 1.00.



Appendix D – Energy Reuse Factor (ERF) Measurement Details

Increasingly in data centers, the energy from the data center is being reused in other parts of the facility or campus with beneficial results. The benefits of energy reused within the data center are captured by the PUE metric. Therefore the purpose of ERF is to incent reuse of energy outside of the data center rather than rejection of energy. ERF is a metric that identifies the portion of energy that is exported for reuse outside of the data center. For example, reuse energy includes energy that is exported outside of the data center to another area within a mixed-use building or to another facility. The basic equation for ERF is as follows:

$$ERF = \frac{\text{Reuse energy outside of the data center}}{\text{Total Data Center Source Energy}}$$

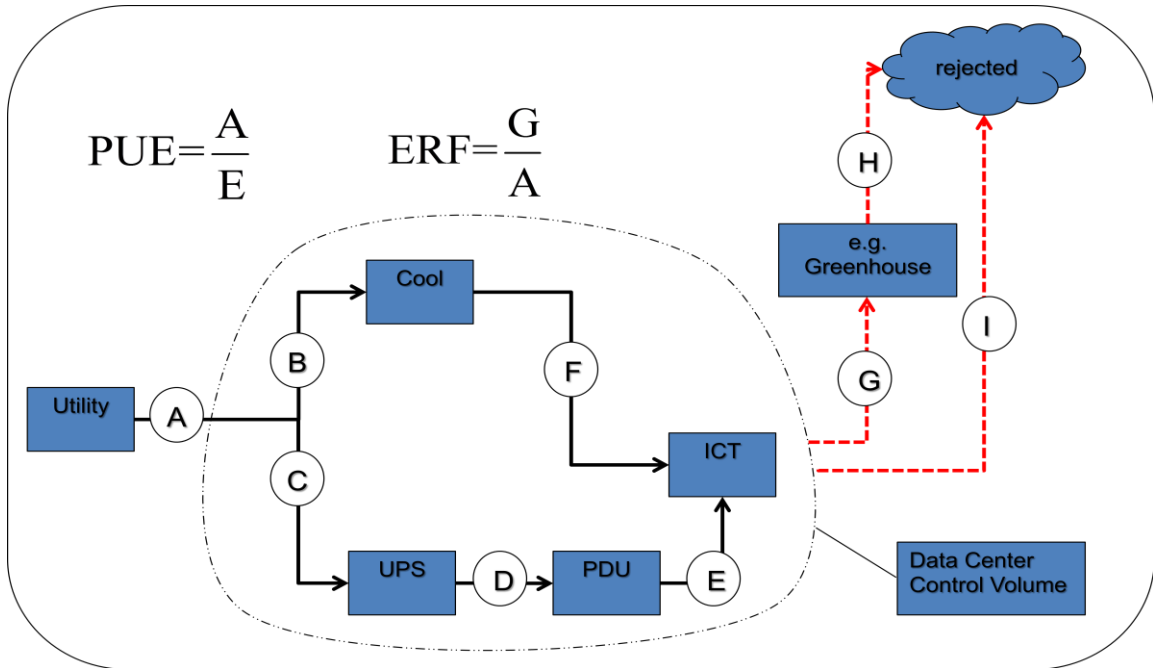
ERF will range from 0.0 to 1.0. The value at 0.0 means no energy is exported from the data center for reuse, while a value of 1.0 means all of the energy brought into the data center is reused outside of the data center.

With ERF, the concept of a control volume must be used. In simplest terms, the control volume is the imaginary boundary around the data center and its infrastructure support areas, such that when energy crosses this boundary, it needs to be accounted for. In Example K, the control volume is indicated by the dashed line.

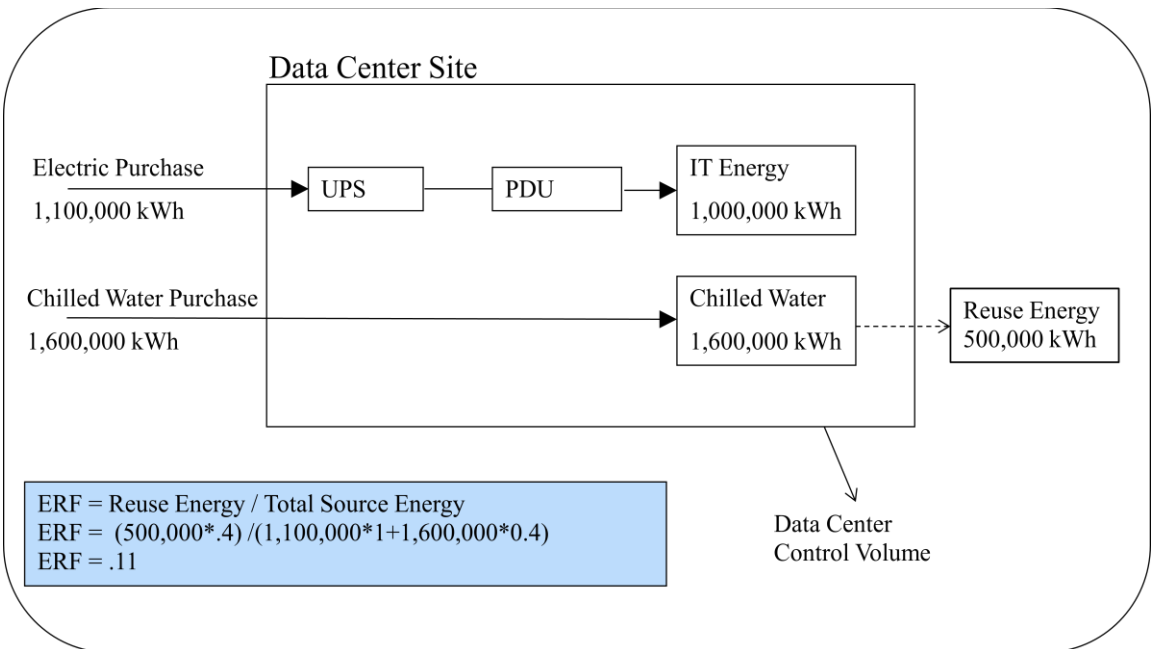
To compute ERF, any energy used by the data center that leaves the control volume for use elsewhere, is considered Reuse Energy. In Example K, the Reuse energy is denoted by (G), and should not be confused with the reject energy (I). Total energy consumed by the data center is identical to total energy as defined in PUE and includes all energy sources that enter the control volume as denoted by (A). The source of the reuse energy must be known to enable equitable calculations. The numerator is the re-use energy, also expressed in source energy. This captures all energy that leaves the control volume. If energy leaves the control volume in the same form as it entered (e.g. extra chilled water that is passed along to another building), then the standard source energy factors from Table 1 are used. However, if the energy that is reused is of a different form because it was created within the data center, then the actual COP or efficiency of production must be used to determine the correct factor.

Finally, while not captured within ERF it is important to consider the intrinsic value of the reuse energy (e.g. hot air versus hot water) and how the energy is actually re-used after it leaves the control volume. One should ensure that the process overhead to reuse the energy does not exceed the equivalent direct use of an energy source. The net total energy consumption should be less when reusing energy.

- Example K: ERF showing the data center control volume.



- Example L: ERF showing Electric & Chilled Water Purchase – Reuse from Chilled Water.



Appendix E – Carbon Usage Effectiveness (CUE) Measurement Details

CUE is a metric to understand the carbon dioxide emission equivalents (CO₂eq) from energy associated with a data center. There are many commonly accepted international protocols that provide direction for quantifying total emissions of any type of facility. For a data center in particular, CUE is a recommended metric because it evaluates the total GHG relative to the IT energy consumption. Whereas an office building may be most interested in GHG per square foot, and an automobile manufacturing plant may be interested in GHG per automobile produced, for the data center, this Task Force recommends that GHG is evaluated relative to the IT energy consumption, using CUE.

Consistent with the desired outcomes of this Taskforce the scope of CUE includes the emissions from energy consumption and excludes the emissions generated in the manufacturing of the IT equipment, its subsequent shipping to the data center, the construction of the data center, etc. The Taskforce considers the full life-cycle to be important to the overall sustainability of the industry but, for practical considerations, they are excluded from this metric. For now, CUE is specifically limited to Scope 1 and Scope 2 emissions. For more on the definitions of Scope 1 and Scope 2 emissions, refer to: World Resources Institute and World Business Council for Sustainable Development (WBCSD), *A Corporate Accounting and Reporting Standard* (2004) <http://www.ghgprotocol.org/files/ghgp/public/ghg-protocol-revised.pdf>, page 25.

To accomplish this complete inventory of emissions from all energy consumption, a data center must include emissions from all energy sources (Note purchased carbon off-sets, green energy certificates, and renewable energy certificates are excluded from CUE):

- Electricity
- District heat (chilled water, hot water, steam)
- Primary energy sources (natural gas, diesel, bio-gas, etc.)
- Renewable energy produced onsite
 - If renewable energy is produced on-site (e.g. through solar or wind power), then the emissions of this energy depend on whether or not the Data Center owns the rights to the green energy certificate or renewable energy certificate, as defined by a local/regional authority. If these rights have been sold, then the emissions of this energy is equivalent to what the emissions would be with a conventional utility purchase (e.g. grid-electric purchase). If the rights have not been sold, then the emissions for the renewable source are obtained from the references in Table 3.

For Data Centers with electricity as the only energy source, the recommended equation for CUE is:

$$\text{CUE} = \text{CEF} \times \text{PUE}$$

Where:

- CEF is the Carbon Dioxide Emission Factor (kgCO₂eq/kWh) of the site. For all electric data centers the CEF is the single value obtained from Table 3.
- PUE is described in Appendix A.

For Data Centers with multiple energy sources the recommended equation for CUE is:

$$\text{Total CO}_2 \text{ emissions caused by the Total Data Center Energy/ IT Equipment Energy}$$

Where:

- Each type of energy source total CO₂ emissions are added
 - IT Equipment Energy is defined as the Total kWh delivered to the IT Equipment

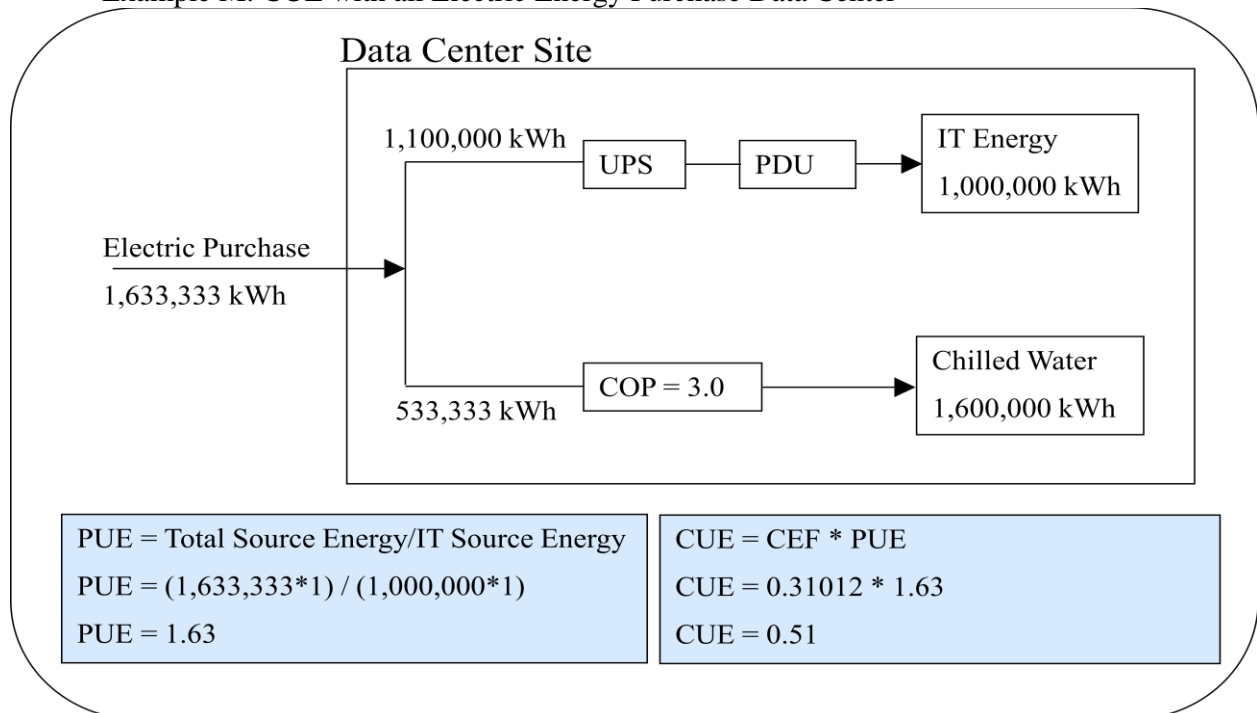
The units of the CUE metric are kilograms of carbon dioxide emission equivalents (kgCO₂eq) per kilowatt-hour (kWh) of IT energy consumption. CUE has an ideal value of 0.0, indicating that no carbon use is associated with the data center’s operations.

Carbon emission factors should be obtained from the government’s published data for the region of operation for that year. All reports for CUE should disclose the source of the CEF used in the calculation.

Region	Recommended Carbon Emission Data for Procured Energy
E.U.	http://re.jrc.ec.europa.eu/energyefficiency/covenantofmayors/seap_guidelines_en-2.pdf http://archive.defra.gov.uk/environment/business/reporting/pdf/100805-guidelines-ghg-conversion-factors.pdf
Japan	http://ghg-santeikohyo.env.go.jp/files/calc/itiran.pdf
U.S.A.	http://www.epa.gov/cleanenergy/documents/egridzips/eGRID2007V1_1_year05_SummaryTables.pdf http://www.energystar.gov/ia/business/evaluate_performance/Emissions_Supporting_Doc.pdf?ac4e-840b

Table 3: Recommended Carbon Emission Data for Procured Energy

- Example M: CUE with all Electric Energy Purchase Data Center



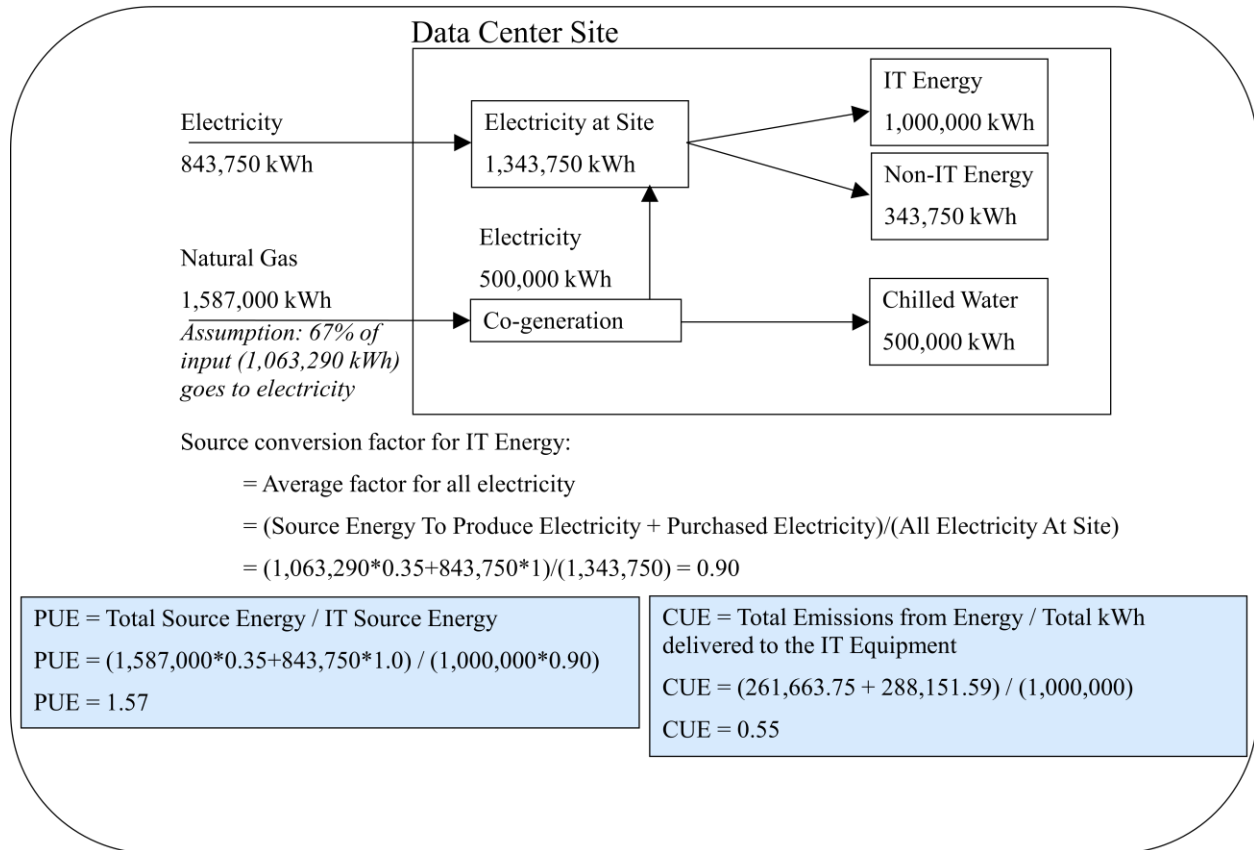
CEF and CUE:

- In this example, let's use US WECC CA as electric source to calculate CUE
- We can use EPA's reference information to get CEF from:
http://www.energystar.gov/ia/business/evaluate_performance/Emissions_Supporting_Doc.pdf?d258-68cc
- Indirect Greenhouse Gas Emission Factors – Purchased Electricity

Electricity Grid by eGRID Subregion	kg CO ₂ /MBtu	kg CH ₄ /Mbtu	kg N ₂ O/MBtu	kg CO ₂ e/MBtu
AKGD (ASCC Alaska Grid)	170.78	0.0036	0.0010	171.1663
AKMS (ASCC Miscellaneous)	71.22	0.0030	0.0006	71.4645
AZNM (WECC Southwest)	166.52	0.0025	0.0022	167.2509
CAMX (WECC California)	90.53	0.0038	0.0008	90.8653
ERCT (ERCOT All)	166.51	0.0024	0.0019	167.1357
FRCC (FRCC All)	162.20	0.0055	0.0020	162.9387
HIMS (HICC Miscellaneous)	178.64	0.0180	0.0029	179.9127

- This WECC CA shows CEF as 90.8653 KgCO₂e/MBtu.
 - 1Btu= 0.293Wh
- CEF will be 90.8653 / 0.293 = 310.12048 KgCO₂e/MWh = 0.31012 KgCO₂e/KWh
- KgCO₂e/KWh for Electricity = 0.31012
- Electricity kWh: 1,633,333 kWh
- Total Annual Energy: 1,633,333 kWh
- Total Annual Emissions from Electricity = 1,633,333 *.31012 = 506,529.23
- Total Annual Emissions from energy = 506,529.23
- CEF = the total annual emissions from all sources divided by the total annual energy.
- CEF = 506,529.23 / 1,633,333 = .31012
- PUE = 1.63 in this example
- CUE, as a function of CEF*PUE = 1.63*.31012 = .51

Example N: CUE at a mixed energy purchase Data Center. (Electricity & Natural Gas)



CUE calculation:

- In this example, let's use US WECC CA as electric source to calculate CUE
- We can use EPA's reference information to get CEF from:
http://www.energystar.gov/ia/business/evaluate_performance/Emissions_Supporting_Doc.pdf?d258-68cc
- Indirect Greenhouse Gas Emission Factors – Purchased Electricity

Electricity Grid by eGRID Subregion	kg CO ₂ /MBtu	kg CH ₄ /Mbtu	kg N ₂ O/MBtu	kg CO ₂ e/MBtu
AKGD (ASCC Alaska Grid)	170.78	0.0036	0.0010	171.1663
AKMS (ASCC Miscellaneous)	71.22	0.0030	0.0006	71.4645
AZNM (WECC Southwest)	166.52	0.0025	0.0022	167.2509
CAMX (WECC California)	90.53	0.0038	0.0008	90.8653
ERCT (ERCOT All)	166.51	0.0024	0.0019	167.1357
FRCC (FRCC All)	162.20	0.0055	0.0020	162.9387
HIMS (HICC Miscellaneous)	178.64	0.0180	0.0029	179.9127

- This WECC CA shows CEF as 90.8653 KgCO₂e/MBtu.
- 1Btu= 0.293Wh
- Then, Electric part of CEF will be 90.8653 / 0.293 = 310.12048 KgCO₂e/MWh = 0.31012 KgCO₂e/KWh

- For the Natural Gas part, CEF can be found at this table of the same EPA link, as 53.200036KgCO2e/MBtu.
- Direct Greenhouse Gas Emission Factors

Table 1 Direct Greenhouse Gas Emission Factors ⁶				
Fuel Type	kg CO ₂ /MBtu ⁷	kg CH ₄ /Mbtu	kg N ₂ O/MBtu	kg CO ₂ e/MBtu
Natural Gas	53.0567	0.0052709	0.0001054	53.200036
Fuel Oil (No. 2)	73.1500	0.0105419	0.0006325	73.207457
Wood	93.8667	0.3162555	0.0042167	101.815222
Propane	63.0667	0.0105419	0.0006325	63.484124
Liquid Propane	63.1620	0.0105419	0.0006325	63.579457

- Btu is required to covert Wh, 1Btu= 0.293Wh
- Natural Gas part of CEF is $53.200036 / 0.293 = 181.5701 \text{ KgCO}_2\text{e/MWh} = 0.18157\text{KgCO}_2\text{e/KWh}$
- KgCO₂e/KWh for Electricity = 0.31012
- KgCO₂e/KWh for Natural Gas = 0.18157
- Electricity kWh: 843,750 kWh
- Natural Gas kWh: 1,587,000 kWh
- Total Annual Emissions from Electricity = $843,750 * .31012 = 261,663.75$
- Total Annual Emissions from NG = $1,587,000 * .18157 = 288,151.59$
- Total Annual Emissions from energy = $261,663.75 + 288,151.59 = 549,815.34$
- CUE, by definition, *Total CO₂ emissions caused by the Total Data Center Energy/ Total kWh delivered to the IT Equipment* = $549,815.34 / (1,000,000) = .55$

Appendix F – Holistic Framework

A holistic framework approach enables awareness of the effect of changes made to the data center specific to the various efficiency metrics. For example, one improvement at a data center that is targeted to improve a specific performance metric could have the result of making another metric look worse. A holistic framework helps the operator keep in mind the effects on all metrics simultaneously.

The Desired Outcomes section lists following three aspects of energy efficiency (or reduction of carbon emissions) of a data center. A Holistic framework is a way to grasp multiple metrics for energy efficiency of a data center collectively:

Outcome (1.a) – IT – Measure the potential IT work output compared to expected energy consumption; and measure operational utilization of IT Equipment.

Outcome (1.b) – Data center facility and infrastructure – Measure the data center infrastructure and efficiency (Power Usage Effectiveness - PUE)

Outcome (2) – Measure renewable energy technologies and re-use of energy to reduce carbon.

To help understand and improve energy efficiency and GHG Emissions of data centers, it is useful to view all these aspects in a single chart. A spider or radar chart such as Figure 1 is a way to view the various metrics in a holistic framework. In the spider chart, metrics for all the Desired Outcomes (1.a), (1.b) and (2) are distributed to its axes to evaluate total energy efficiency of a data center.

As a holistic framework, each Desired Outcome [as listed at above; (1.a), (1.b) and (2)] should have at least one, or more where applicable, metric in the spider chart. At this time the Taskforce has not provided a recommendation for Desired Outcome 1.a. Once agreement is reached and a recommendation provided, the recommended metric(s) should be included into the holistic framework. The number of metrics (axes) may vary depending on the selection of metrics chosen by the data center operator. Figures 2 and Figures 3 shows variations of the spider chart with 4 and 5 axes, respectively. In Figure 2, two metrics are adopted to Outcome 1.a. In Figure 3, three metrics are adopted to Outcome 2. These metrics evaluate different aspects of Outcome 1a and Outcome 2. Once the metrics are selected, the operator will also need to identify a start and end point for each axis. In some cases, there are theoretical maximum and minimum values (e.g. GEC can only range from 0.0 to 1.0). In other cases, there are not clean maximum values (e.g. there is no maximum for PUE). Therefore, the axis ends will have to be established based on target values or other estimates. The selection of metrics and the selection of the axis end points both establish an implicit weighting among the metrics, therefore care should be taken during this process.

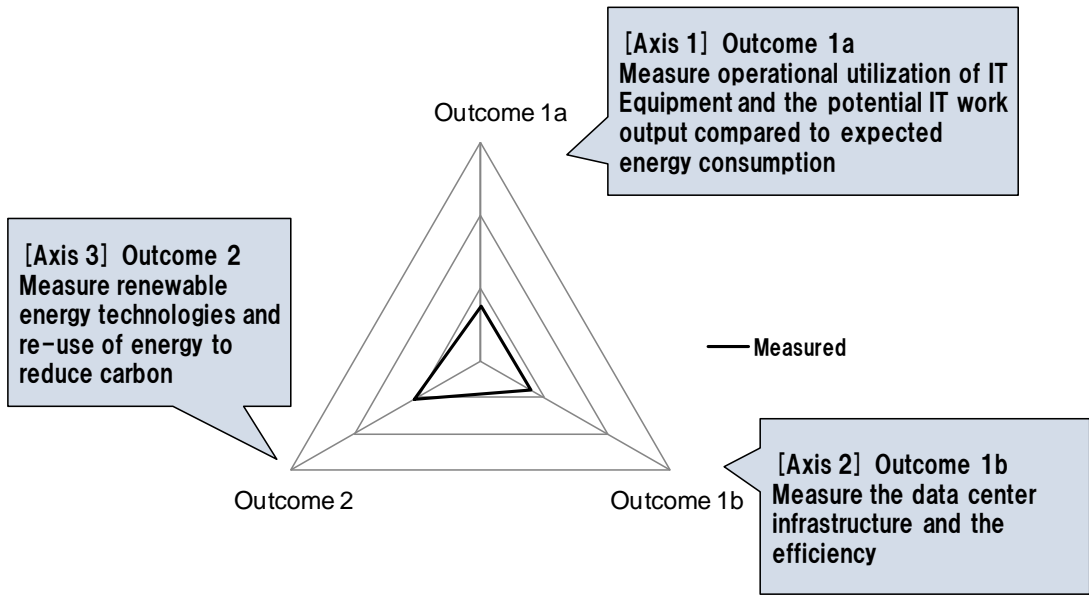


Figure 1: A possible expression of “Holistic Framework”

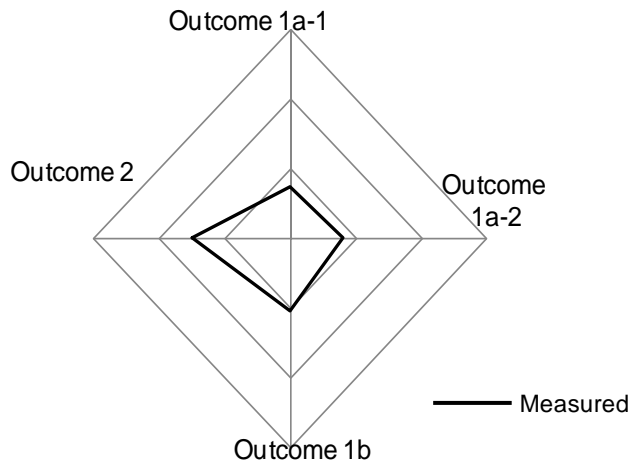


Figure 2: Possible variations of a spider chart expression

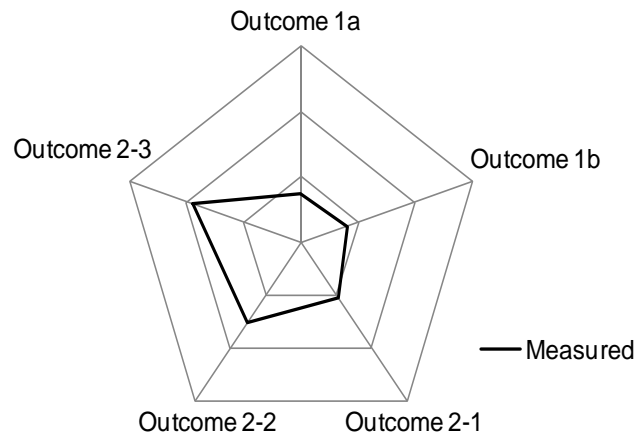


Figure 3: Possible variations of a spider chart expression

The spider chart approach offers several benefits, by providing a combined visualization of all metrics. In particular, by looking at a spider chart, a data center operator can see which metric is worst – this may be the metric with the greatest area for improvement. Another benefit is that the spider chart lets an operator visualize the effects of an efficiency improvement on all metrics. The goal is to move all metrics in the same direction toward increased efficiencies. Therefore, it would be important after investing in changes at a data center to review the spider chart and confirm that all metrics have improved. Finally, the spider chart can be used not only to plot current measured performance, but also to plot target performance, so that progress towards a target can be tracked for all metrics at once.

Appendix G – Data Center Energy Productivity (DCeP)

Data center energy productivity (DCeP) is an equation that quantifies useful work that a data center produces based on the amount of energy it consumes. “Useful work” is a sum of tasks that are completed in a specified period of time, where each task is weighted based on a specified relative value. In this way, more-valued tasks receive greater weighting in the calculation of useful work, and less-valued tasks receive lesser weighting. DCeP allows each user to define useful work and the weighting for various forms of useful work (if measuring more than one type) that apply to that user’s business. For example, a retail business may use the number of sales as its measure for useful work, an online search company may use the number of searches completed, and so on. The definitions can get as granular as necessary for the entity using the equation: web pages served, database transactions executed, emails served, etc.

Mathematically, DCeP can be expressed as:

DCeP = Useful Work Produced / Total Data Center Source Energy Consumed Producing this Work

Where:

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

M is the number of tasks initiated during the assessment window

V_i is a normalization factor that allows the tasks to be summed numerically

$T_i = 1$ if task i completes during the assessment window, and $T_i = 0$ otherwise

$U_i(t, T)$ is a time-based utility function for each task

t is elapsed time from initiation to completion of the task

T is the absolute time of completion of the task

The DCeP denominator, Total Data Center Source Energy Consumed Producing this Work, is identical to the PUE numerator.

Note that Useful Work Produced is defined as the sum over i of all tasks 1 through M initiated within the assessment window multiplied by a time-based utility function $U_i(t, T)$. The factor V_i assigns a normalized value to each task so that they may be algebraically summed. T_i eliminates all tasks that are initiated either prior to the assessment window or within the window but do not complete.

For further details, see The Green Grid Association published material:

- <http://www.thegreengrid.org/Global/Content/white-papers/Framework-for-Data-Center-Energy-Productivity>

Appendix H – Data Center Productivity Proxies

While DCeP represents data center productivity in terms that are meaningful to a specific data center, a productivity proxy is a relatively simple metric that aims to approximate data center productivity generically.

A productivity proxy should address Outcome (1.a):

Outcome (1.a) – IT – Measure the potential IT work output compared to expected energy consumption, and measure the operational utilization of IT equipment.

Although the Taskforce did not reach consensus for a recommendation, the following is the approach the Taskforce followed to address Outcome (1.a). Through industry research and group discussion, the Taskforce began reviewing the following metrics:

- Useful work self-assessment & reporting
- Data center energy productivity (DCeP) by energy checker
- Data center energy productivity (DCeP) sample load
- Network traffic (bits) per kilowatt-hour
- Weighted CPU utilization – SPECint_rate
- Weighted CPU utilization – SPECpower
- Compute units per second (CUPS)
- Operating system workload efficiency
- IT equipment energy efficiency (ITEE) x IT equipment utilization (ITEU)

Independently, members of the Taskforce undertook structured experiments to assess the various proxies, and they performed industry trials. Based on a general discussion about accuracy and ease of use, the Taskforce decided to have more detailed discussions on three metrics: network traffic (bits) per kilowatt-hour, weighted CPU utilization – SPECint_rate, and IT equipment energy efficiency x IT equipment utilization.

Network traffic (bits) per kilowatt-hour is calculated as:

$$\text{Outbound bits} / \text{data center energy}$$

Weighted CPU utilization – SPECint_rate is calculated as:

$$(\text{SPECint_rate} * \text{CPU utilization}) / \text{data center energy}$$

IT equipment energy efficiency x IT equipment utilization is calculated as:

$$(\text{Benchmark performance} / \text{rated power}) * (\text{IT energy} / \text{IT rated energy})$$

For further details regarding the three metrics reviewed by this Taskforce, see the associated published material:

CPU SPECint_rate: <http://www.thegreengrid.org/library-and-tools>

ITEE x ITEU: http://home.jeita.or.jp/greenit-pc/e/topics/release/100316_e.html

Network (bits): <http://www.thegreengrid.org/library-and-tools>

These three metrics were discussed further within industry forums, Taskforce technical review, and additional experiments. The three metrics were then evaluated through the following specific evaluation criteria and finally through a facilitated pros and cons review.

Evaluation Criteria

The following criteria were used to analyze the three proxies. The list is included below to indicate the level of due diligence conducted by the Taskforce.

- Operational measurement: Is the proxy based on a measurement taken during data center operations?
- Track actual productivity: Does the proxy positively correlate with actual productivity in the data center?
- Representative of desired Outcome (1.a): Does the proxy accurately represent Outcome (1.a) as defined by the Taskforce?
- Relevance: Does the proxy provide relevant and useful information to the target audience?
- Comparable: Does the proxy allow normalized comparison between data centers, such as within a single company or market sector or across market sectors?
- Time stable: Can the proxy be used to compare past performance with present performance?
- Perverse incentives: Does the proxy definition account for perverse incentives it could create? How impactful are those perverse incentives?
- Incent energy efficiency: Does the proxy provide an incentive to reduce energy consumption for the same work load?
- Ease of use: Is the proxy easy to implement and use?

Pros and Cons

The evaluation of the proxies against the above criteria revealed a number of pros and cons associated with each proxy. The Taskforce identified the following list of major pros and cons.

Metric	Pros	Cons
CPU SPECint_rate	<ol style="list-style-type: none"> 1. Correlates well with actual work 2. Easy to understand 3. Using the well-known benchmark enables easier comparison 	<ol style="list-style-type: none"> 1. Does not include storage and networking 2. Difficult to collect required data (CPU utilization) 3. Does not include 100% of servers
ITEE x ITEU	<ol style="list-style-type: none"> 1. Relatively easy to calculate 2. Includes storage and networking 3. Benchmark data is available 	<ol style="list-style-type: none"> 1. Concerns with implicit weighting factor for server, storage, and network 2. Concern with storage and network productivity measure (capacity) 3. The metric is heavily reliant on catalog data rather than measured values
Network (bits)	<ol style="list-style-type: none"> 1. Easy to understand and calculate 2. Easy to obtain information 3. Correlation to work and ease of use is good 	<ol style="list-style-type: none"> 1. Depending on the data center type, the relevance of the metric can be low (such as for a research data center) 2. Too simple, less focus on how much work is complete inside the data center 3. Comparison within market sector is difficult