

Harmonizing Global Metrics for Data Center Energy Efficiency

データセンタのエネルギー効率に関する指標の世界協調について

Global Taskforce Reaches Agreement on Measurement Protocols for GEC, ERF, and CUE – Continues Discussion of Additional Energy Efficiency Metrics

October 2, 2012

世界的タスクフォースはGEC、ERF、CUEの測定方法について合意に達するとともに、
追加的なエネルギー効率指標に関する議論を継続する
2012年10月2日

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 their performance with energy efficiency and Greenhouse Gas (GHG) Emission metrics. However, even with the global presence of many companies, these metrics are often 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: U.S. Department of Energy's Advanced Manufacturing Office and Federal Energy Management Programs, U.S. Environmental Protection Agency's ENERGY STAR Program, European Commission Joint Research Center Data Centers Code of Conduct, Japan's Ministry of Economy, Trade and Industry, Japan's Green IT Promotion Council, and The Green Grid.

A joint statement in February 2011 highlighted the agreement reached specific to measurement protocols for PUE and further goals and guiding principles for collaboration. Since then, this work has been expanded to provide measurement guidelines and next steps for three additional metrics; Green Energy Coefficient (GEC), Energy Reuse Factor (ERF), and Carbon Usage Effectiveness (CUE). This current document reflects agreements reached as of October 2, 2012. The group intends to continue collaboration as an ongoing effort to improve Data Center Energy efficiency and GHG Emission efficiencies.

【仮訳】 21世紀において、データセンタは事業運営において非常に重要な役割を担うものとなった。需要が増加しエネルギー価格が上昇するなかで、重要な役割を担うこれらの設備の所有者や管理者にとって、エネルギー効率と温室効果ガス排出の指標を利用して設備の性能を評価し向上させることは必要不可欠である。しかしながら、多数の世界的企業が存在するにもかかわらず、多くの場合、これらの指標は世界レベルでは一貫した形で利用されていない。

この一貫性がない状況に対して、データセンタ業界における世界的なリーダーが、主要なエネルギー効率と温室効果ガス排出の指標の標準的測定方法と報告方法の合意を目指して、チームを作り定期的に会議を開催してきた。参加組織は、米国エネルギー庁の「先進製造技術局と連邦エネルギー管理プログラム」、米国環境保護庁の「エネルギースター・プログラム」、欧州委員会共同研究センターの「データセンター・コードオブコンダクト（行動規範）」、日本の経済産業省とグリーンIT推進協議会、そしてグリーングリッドである。

2011年2月の合同声明では、PUE測定基準に関する合意と、さらなる協調に向けた目標と基本理念を強調した。それ以降、このチームは、3つの追加的指標—グリーンエネルギー利用率（GEC）、エ

エネルギー再利用係数(ERF)とカーボン利用効率 (CUE)の測定ガイドラインと今後の展開を提供するところまで到達した。本文書は2012年10月2日の会議での決定事項を反映している。このチームは、データセンタのエネルギー効率の向上と温室効果ガス排出係数の改善に向けた継続的な取り組みに対し、今後も協調を続ける予定である。

Goal

Share global lessons and practices with an objective of arriving at a set of metrics, indices, and measurement protocols which can be formally endorsed or adopted by each participant organization to improve data center energy efficiency and GHG Emissions globally. This 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 on-going dialog for development of additional metrics

【仮訳】 目標

データセンタのエネルギー効率と温室効果ガス排出を世界規模で改善するため、これまでの世界規模の経験と取り組みを共有し、各参加機関が公式に承認し導入することができる指標と測定基準を確立することを目標とする。特に、以下の具体的な目標を含むこととする：

1. 初期段階の指標の特定
2. 各指標の定義
3. 各指標の測定プロセスの定義
4. 追加指標の開発に向けた意見交換の場の設置

Desired Outcomes

There are several desired outcomes of the Taskforce's activities.

Outcome (1) – Effective energy efficiency metrics that measure the actual IT work output of the data center compared to actual energy consumption. It is of note that in the process to define 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 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.

【仮訳】 期待される成果

タスクフォースの活動では、以下のような成果をめざす：

成果(1) - 実際のエネルギー消費量に対する実際のデータセンタのIT機器の仕事量を測定する効果的なエネルギー効率指標。IT機器の仕事量を定義する際、以下の中間測定方法が定義され、かつ/または有効である。

成果(1. a) - IT機器について： IT機器の定格エネルギー消費量に対する仕事能力を測定する。また、IT機器利用率を測定する。

成果(1. b) - データセンタの設備とインフラについて： データセンタのインフラ（付帯設備）の効率（PUE = Power Usage Effectiveness）を測定する。

成果(2) - 炭素排出量削減のため、再生可能エネルギーと再利用エネルギーの量を測定する。

Guiding Principles

It is recommended by all that the development of metrics to address Outcomes (1.a), (1.b), and (2), should form a holistic framework to help understand interactions among metrics. The Taskforce recommends viewing the various data center efficiency metrics in a multi-parameter framework, such as a spider chart. Viewing the metrics in a multi-parameter framework helps owners and operators identify the effect of changes made to the data center specific to the various efficiency metrics. This approach is further outlined in Appendix F. Along with the energy efficiency and GHG Emission measurements and metrics, all 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.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 the 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 PDU. At a minimum IT energy measurements should be measured at the output of the 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 detail on measurement guidelines have been added in Appendix A for PUE measurements. The additional detail provides guidelines specific to equitable measurements of PUE with various designs; using multiple energy inputs (including renewable energy), on-site generation, and re-use of energy.

【仮訳】 ガイドライン

成果 (1.a) と (1.b), そして (2) に取り組むための指標の開発においては、それらの指標がどのように相互に関係しているかを理解するために、総合的な評価体系が形成されることが望ましい。タスクフォースは、例えばスパイダーチャート（レーダーチャート）のようなマルチパラメーター体系を用いて様々なデータセンタの効率指標を見ることを勧める。そうすることによって、データセンタ所有者や事業者は、様々な効率指標に基づきデータセンタを改善することの効果を理解してもらうことができる。これについては附録Fに記述している。エネルギー効率と温室効果ガス排出の指標においては、全員が絶対量を基本とすることが望ましい。エネルギー効率の改善や温室効果ガス排出プログラムの試みは、エネルギー消費や温室効果ガス排出の絶対量削減につながるべきである。

タスクフォースは以下のように議論をまとめ合意に達した：

成果 (1. b) –データセンタは 次のような原則によるPUE測定を始めることが推奨される。

- ソースエネルギーを用いたPUEが、エネルギー効率を測る指標として望ましい。なお、PUEはデータセンタの全消費エネルギーをIT機器の消費エネルギーで割ったものである。
- 最終的にIT機器（サーバ、ストレージ、ネットワーク等）の負荷の直接測定を可能にするため、業界はIT機器のエネルギー測定能力を改善すべきである。IT機器の消費エネルギーの測定をPDUの出力にて実施することが推奨される。少なくとも、IT機器の消費エネルギーの測定はUPSの出力にて行うべきである。
- データセンタにおいては、全消費エネルギーの測定はutility handoff（ユーティリティの責任転換箇所；施設と外部の境界）における全エネルギー源を含めて行うべきである。全消費エネルギーは、IT機器の消費エネルギーに加え空調や照明、他のインフラの消費エネルギーを含むべきである。

- 測定ガイドラインに関する付加的な詳細が、下記のPUE測定に関する附録Aに付け加えられている。この付加的な詳細は、異なる種類のエネルギー（再生可能なエネルギーを含む）の利用やオンサイト発電、エネルギーの再利用など、多様な事例におけるPUEの公平な測定方法に関して、具体的なガイドラインを提供する。

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 (kWh) divided by 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. Total energy consumed at 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 total energy consumed by the data center. Reuse energy is measured as it exits the data center control volume see Appendix D. 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.

成果 (2) –データセンタは次のような原則によるGEC、ERF、CUEの測定を始めることが推奨される：

- GEC はグリーンエネルギーを利用した電力使用割合を表す指標である。GEC は、データセンタで消費されるグリーンエネルギー (kWh) をデータセンタで消費される全エネルギー (kWh) で割ることにより算定される。GEC で対象とするグリーンエネルギーは、地方/各国の当局によって定義され、データセンタがグリーンエネルギー証明書または再生可能エネルギー証明書の版権を所有する再生可能エネルギーと定義される。これについては附録Cにさらに詳しく記述している。データセンタの全エネルギー消費量は全ソースエネルギーであり、PUE の分子と同一である。
- ERF はデータセンタ外で再利用するために取り出されるエネルギー量を明確にする指標である。ERF は再利用エネルギーをデータセンタの全消費エネルギーで割ることにより算定する。再利用エネルギーはデータセンタのコントロールボリュームから外部に出る

場所で測定する（附録 D 参照）。データセンタの全エネルギー消費量は、PUE の分子と同様に計算された、全ソースエネルギーである。

- CUE はデータセンタの IT エネルギー消費に対する温室効果ガス排出量を測ることができ、指標である。CUE はデータセンタ全体の二酸化炭素排出量（CO₂eq）を全体の IT エネルギー消費量で割ったものとして算定される。データセンタが電力のみを使用する場合は、CUE はデータセンタの炭素排出係数（CEF）と PUE の積と数学的に同等である。附録 E にさらに詳しい算出方法について記述している。

Progress to Date and Next Steps

Desired Outcomes:

Outcome (1) – Measure the actual IT work output of the data center compared to actual energy consumption. At this time the Taskforce is primarily focusing on Outcome (1.a).

Outcome (1.a) – IT – Measure the potential IT work output compared to expected energy consumption; and measure operational utilization of IT Equipment. Over this past year the Taskforce has reviewed the following metrics and continues to evaluate their applicability through industry trials:

IT Equipment Efficiency (ITEE) & IT Equipment Usage (ITEU). For further details see the published GIPC material:

- http://www.greenit-pc.jp/e/topics/release/100316_e.html

Data Center Energy Productivity (DCeP) Proxies, Bits per kWh Proxy, CPU Utilization Proxies, OS instance Proxy. For further details see The Green Grid published material:

- <http://www.thegreengrid.org/en/Global/Content/white-papers/Productivity%20Proxy%20Proposals%20Feedback%20Interim%20Results>

【仮訳】 これまでの進展と今後の展開

期待される成果に関して：

成果（1） – 実際のエネルギー消費量と比較した、実際のデータセンタのIT機器の仕事量を測定する。現時点ではタスクフォースは主として成果（1.a）に集中している。

成果（1.a） – IT機器について： IT機器の定格エネルギー消費量に対する定格仕事能力を測定する。また、IT機器利用率も測定する。過去1年の間、タスクフォースは以下の指標を検討し、業界での試行を通じてそれらの指標の適用性に対する評価を続けている。

IT機器電力効率（ITEE）とIT機器利用率（ITEU）

さらに詳しい内容はGIPCの資料を参照。

- http://www.greenit-pc.jp/e/topics/release/100316_e.html

データセンターエネルギー生産性 (Data Center Energy Productivity, DCeP) プロキシ、Bits per kWh プロキシ、CPU稼働率 (CPU Utilization) プロキシ、OS instance プロキシ。詳細はグリーングリッドによる資料を参照

<http://www.thegreengrid.org/en/Global/Content/white-papers/Productivity%20Proxy%20Proposals%20Feedback%20Interim%20Results>

Outcome (1.b) – Data center facility and infrastructure – Measure the data center infrastructure and efficiency (PUE). With the above revised guiding principles, there are no further outstanding PUE related items for discussion at this time.

Outcome (2) – Measure renewable energy technologies and re-use of energy to reduce carbon. With the above revised guiding principles, there are no further outstanding items for discussion at this time.

成果 (1.b) - データセンターの設備とインフラについて： データセンターの付帯設備電力効率（PUE）を測定する。上記の改定ガイドラインを作成した結果、PUEに関する顕著な論点は現在のところ存在しない。

成果 (2) - 炭素排出量削減のため、再生可能エネルギーとエネルギーの再利用率を測定する。上記の改定ガイドラインを作成した結果、顕著な論点は現在のところ存在しない。

This guidance is meant to provide a status update for the Taskforce’s desired outcomes and to help drive a common understanding of energy efficiency metrics. With continued dialog and additional input by a variety of stakeholders, this guidance will be refined and expanded to maximize its impact on both energy consumption and operational efficiency. There is significant interest and work among the bodies represented to proceed with globally accepted metrics and measurement protocols, providing guidance to range from minimum recommendations to best practices.

The Taskforce has met in the U.S., Italy, and Japan and has recently celebrated three years of collaboration. The Taskforce has confirmed to continue the discussion and collaboration around these metrics toward global harmonization of metrics for data center energy efficiency.

このガイダンスは、タスクフォースの期待する成果に関する状況を更新し、エネルギー効率指標の共通認識を推進するためのものである。本ガイダンスは、エネルギー消費と運用効率における効果を最大にするために、継続的な議論と様々な利害関係者からの追加インプットによりさらに整備、拡充される。最低限の推奨からベストプラクティスまで幅の広いガイダンスを実施しながら世界的に受け入れられる指標や測定基準の整備を進めるということに、参加各機関は極めて高い関心を持って取り組んでいる。

タスクフォースはアメリカ、イタリア、日本にて会議を開催し、最近活動の開始から3年の節目を迎えた。タスクフォースは今後もデータセンターのエネルギー効率に関する世界指標の協調に向けて、指標に関する議論と協同を続けることを確認した。

Participating Organizations

Each organization is represented on the Taskforce, which convenes regularly to advance the progress of the group. A full group of participants from each organization continues to meet in person every 6 to 12 months, as the Taskforce feels it is appropriate based on progress.

参加機関

本会議に参加した全ての機関によってタスクフォースが構成されており、このグループは状況を進展させるために定期的に会議を開催している。各機関からの全ての参加者は、進捗に応じてグループが適当だと判断した時期に6ヶ月から12ヶ月毎に顔を合わせ、会議の開催を継続する。

For further details, please contact:

- The Green Grid: gdcmetrics@lists.thegreengrid.org
- U.S. Department of Energy: <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: http://re.jrc.ec.europa.eu/energyefficiency/html/standby_initiative_data_centers.htm
- Ministry of Economy, Trade, and Industry: <http://www.meti.go.jp/english/index.html>
- Green IT Promotion Council: <http://www.greenit-pc.jp>

List of Appendices

Appendix A – Power Usage Effectiveness (PUE) Measurement Details 10

Appendix B – Power Usage Effectiveness (PUE) Illustrative Calculation Examples 14

Appendix C – Green Energy Coefficient (GEC) Measurement Details 17

Appendix D – Energy Reuse Factor (ERF) Measurement Details 21

Appendix E – Carbon Usage Effectiveness (CUE) Measurement Details 23

Appendix F – Holistic Framework..... 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:

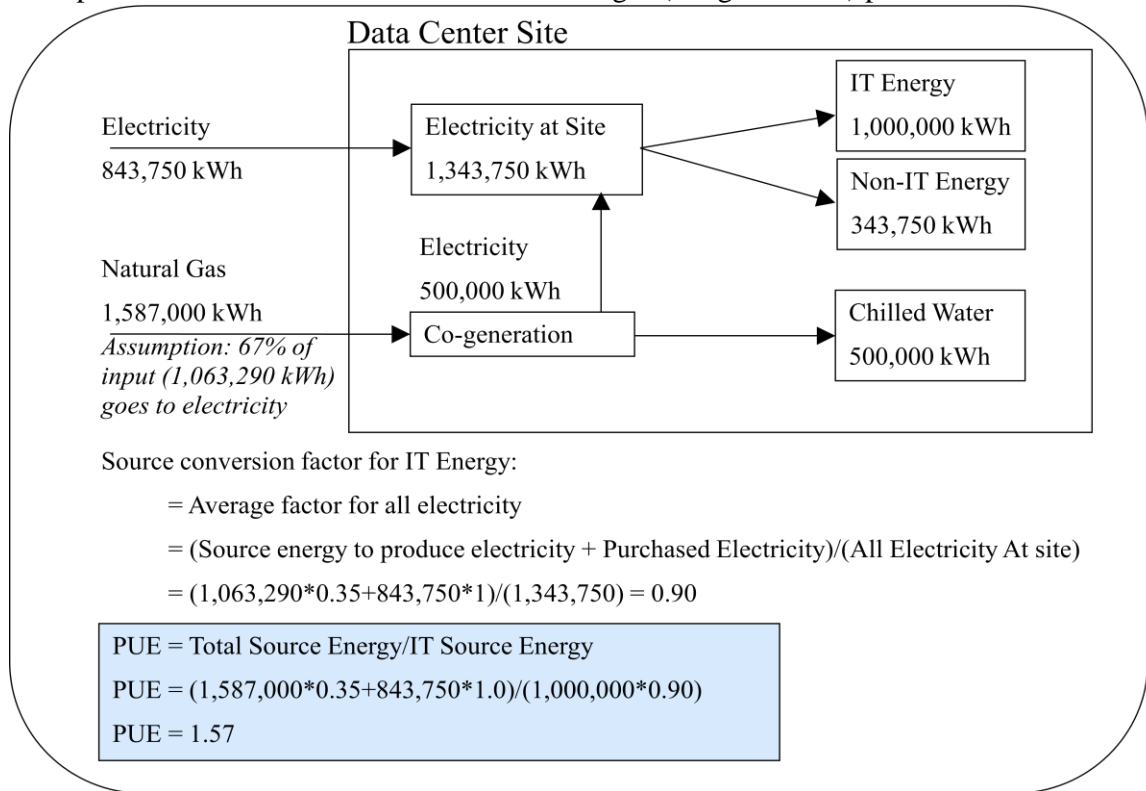
<i>Energy Type</i>	<i>Weighting Factor</i>
Electricity	1.0
Natural gas	0.35
Fuel oil	0.35
Other fuels	0.35
District chilled water	0.4
District hot water	0.4
District steam	0.4

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

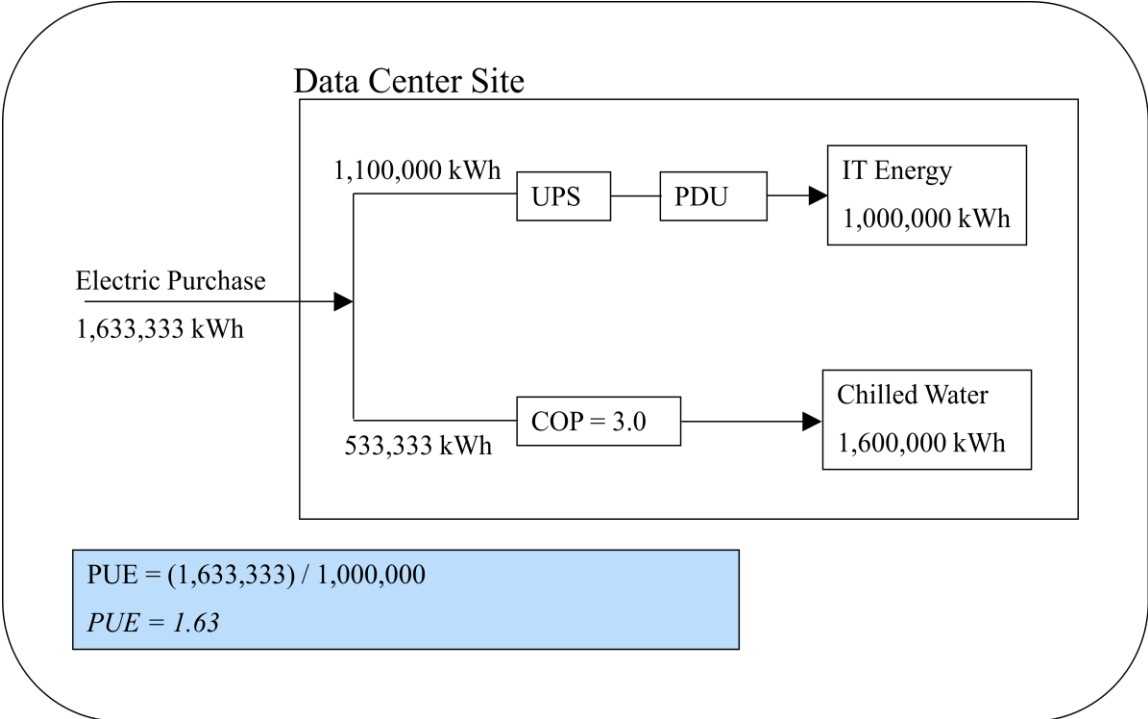
* When excluding any ancillary energy loads this should be declared when reporting PUE.

- 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.

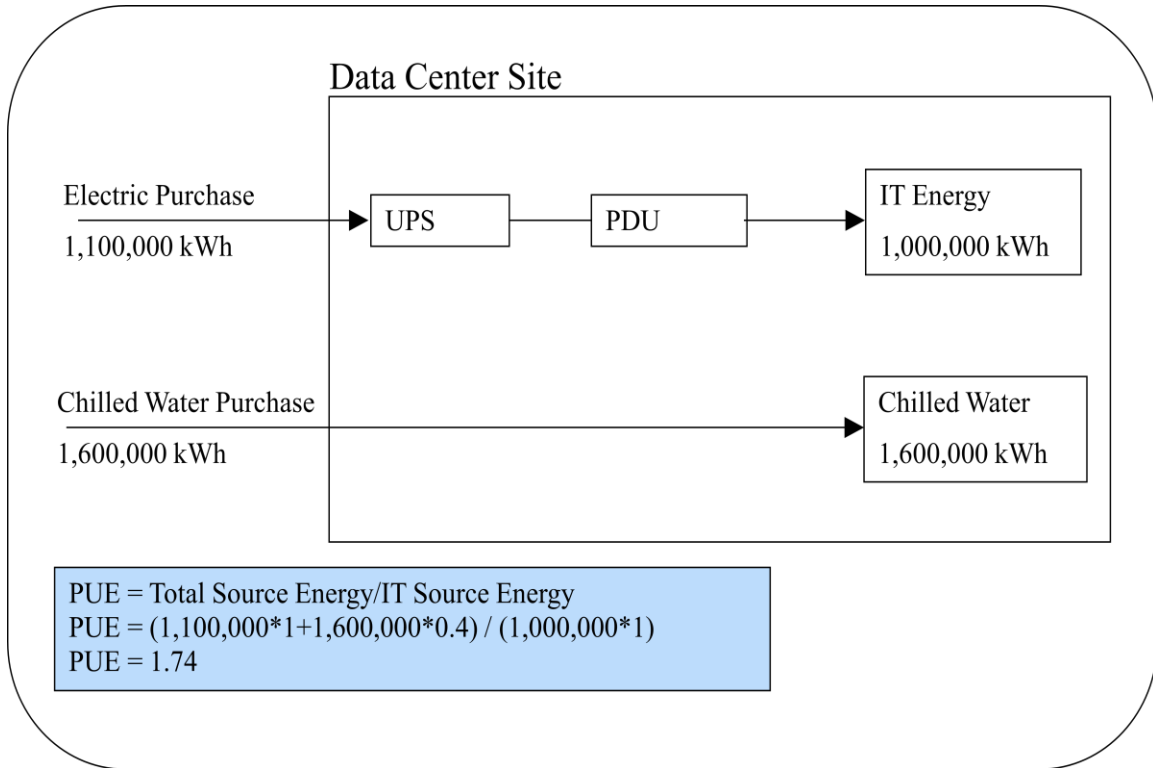
Appendix B – Power Usage Effectiveness (PUE) Illustrative Calculation Examples

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:

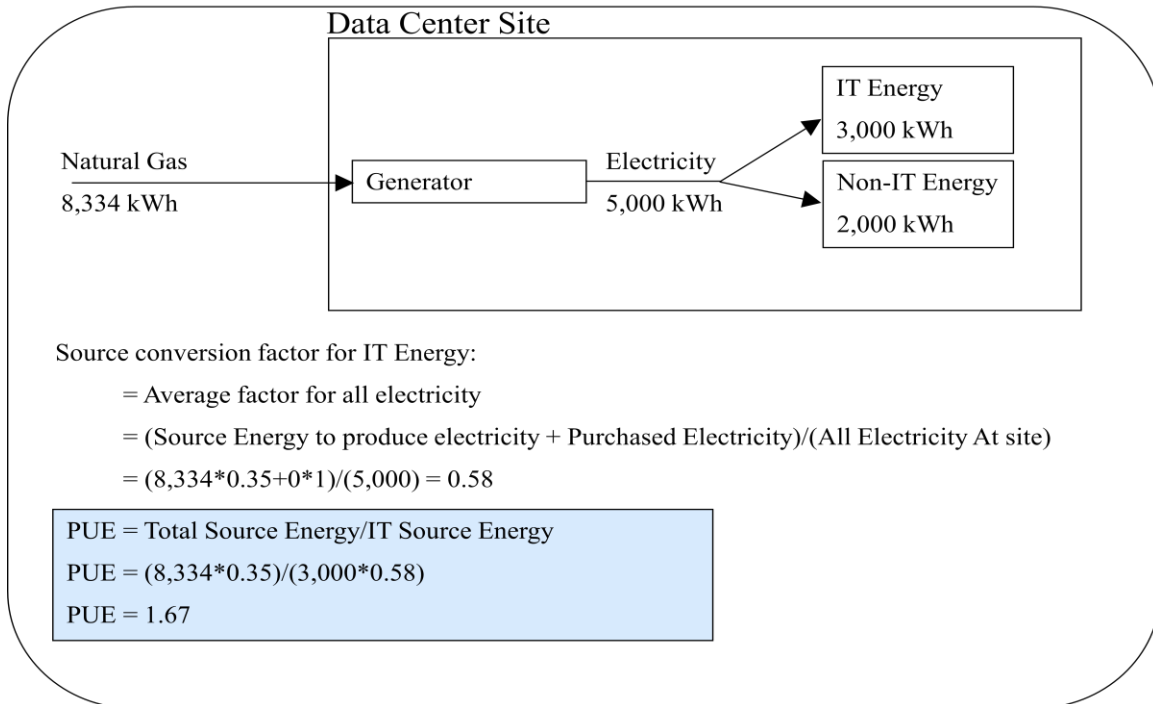
- Example B – Data center with all electric purchase



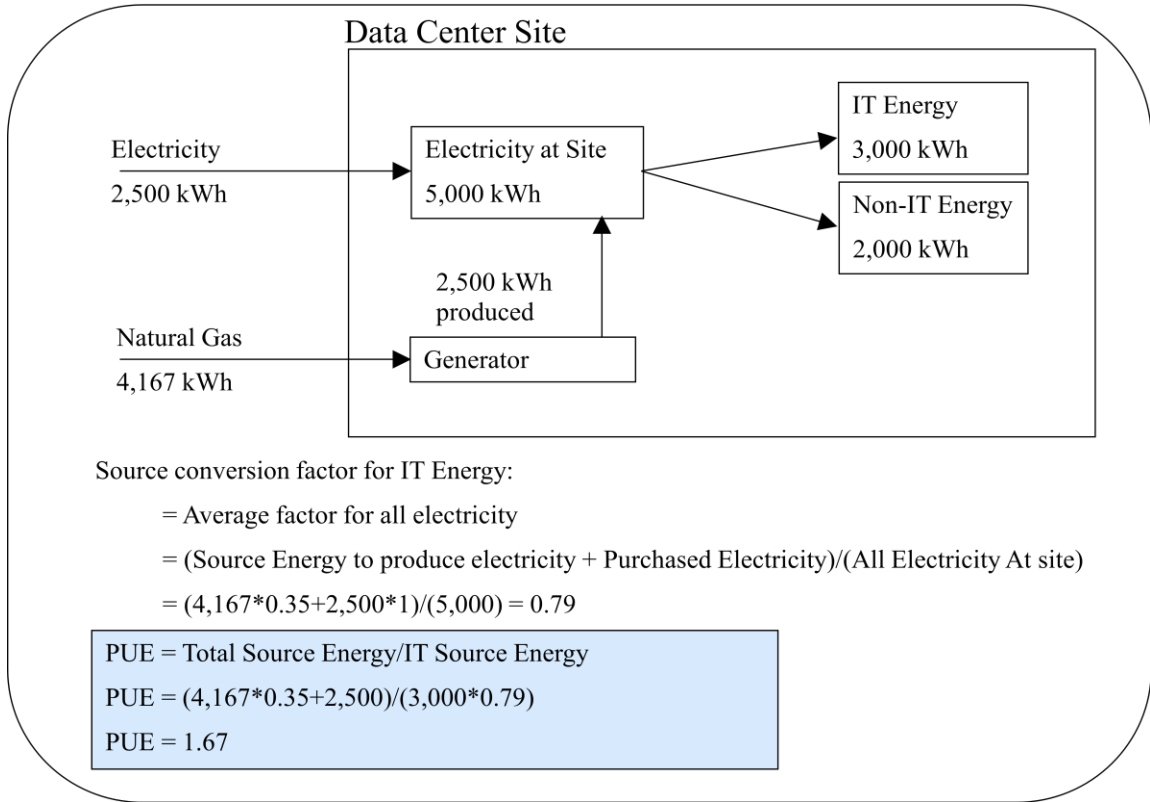
- Example C – Data center with electric and chilled water purchase



- 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:

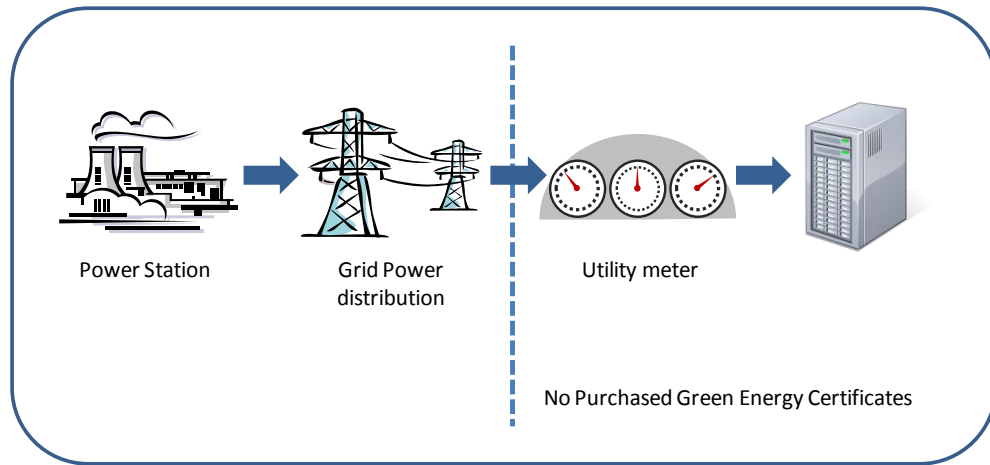
$$GEC = \frac{\text{Green energy used by the data center}}{\text{Total Data Center Source Energy}}$$

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

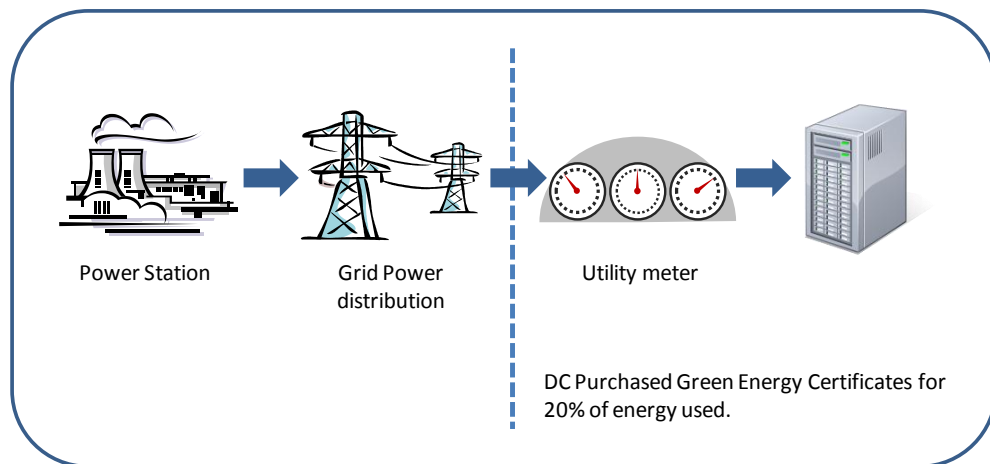
consumed at the data center is identical to the numerator of PUE. As with PUE, all energy shall be reported using the same units, and the recommended unit of measure shall be kWh. Standard thermal conversion factors shall be used to convert to kWh (e.g. 1 kWh = 3.412 kBtu; 1 GJ = 278 kWh). Finally, because 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.

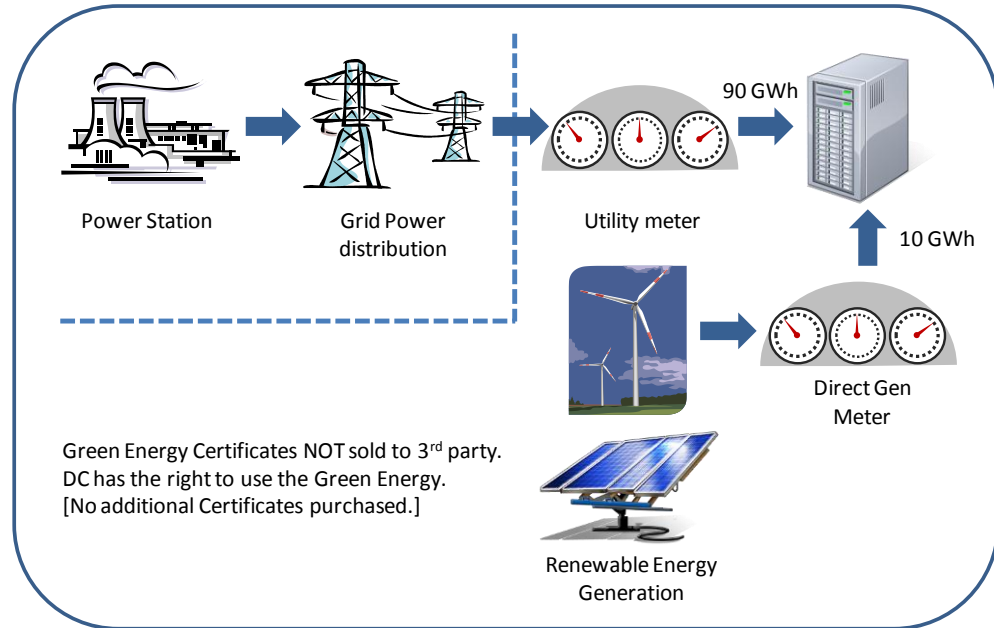
- Example F: Grid energy purchased without Green Energy Certificates: $GEC = 0.00$.



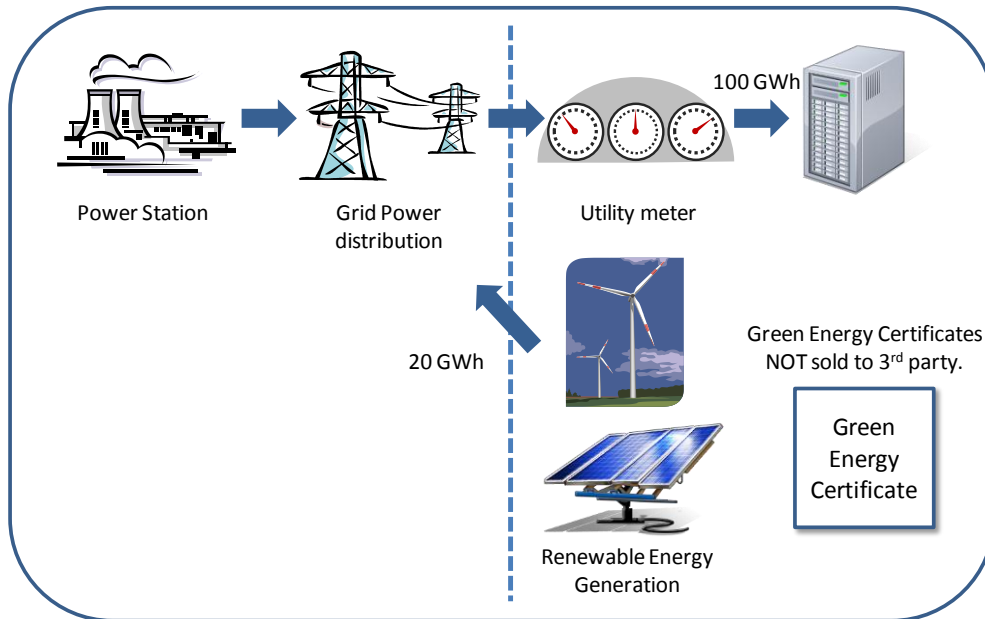
- Example G: Green Energy Certificates purchased and retired for 20% of the energy used by the DC: $GEC = 0.20$



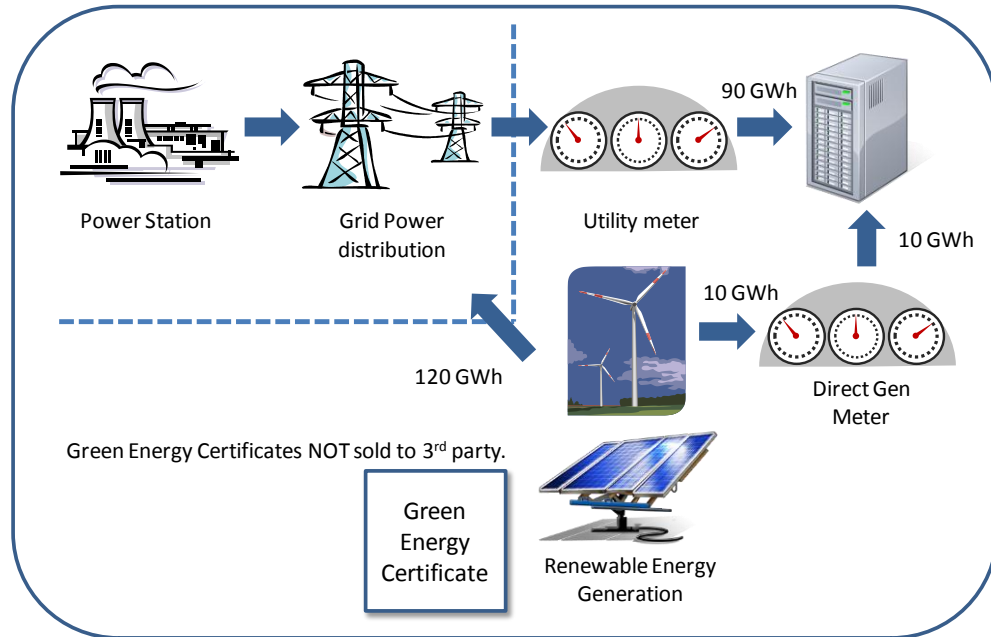
- Example H: Green Energy Certificates for locally generated green energy are retired by the DC: GEC = 0.10.



- 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:

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

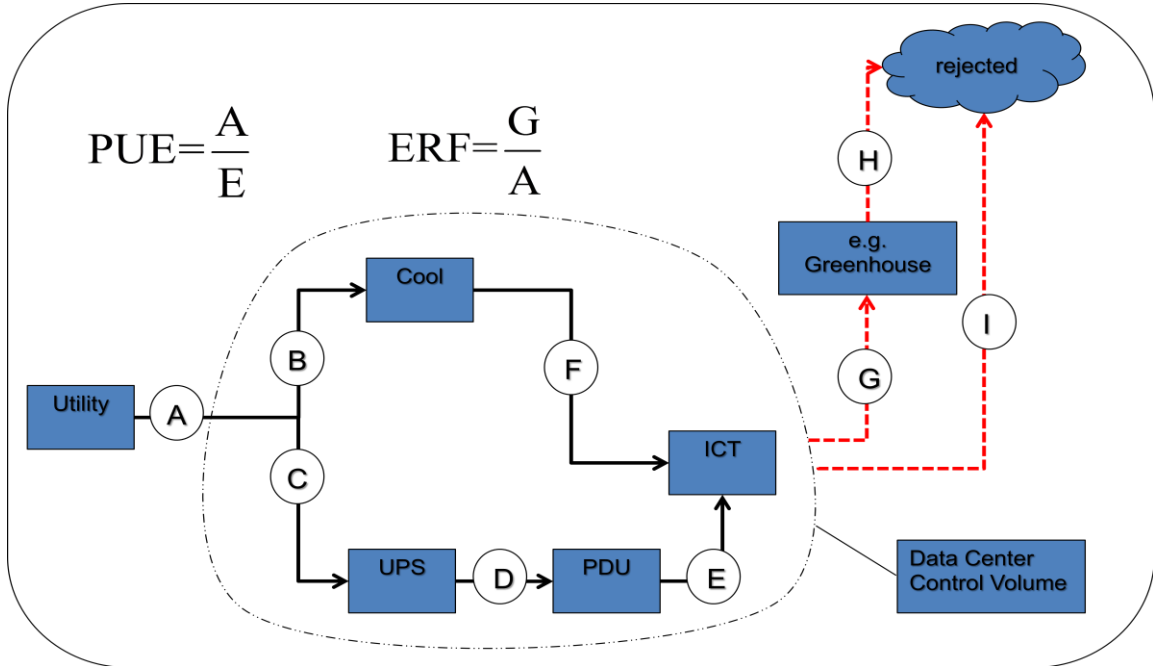
ERF will range from 0.0 to 1.0. The value at 0.0 means no energy is exported from the data center for reuse, while a value of 1.0 means all of the energy brought into the data center is reused outside of the data center.

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.

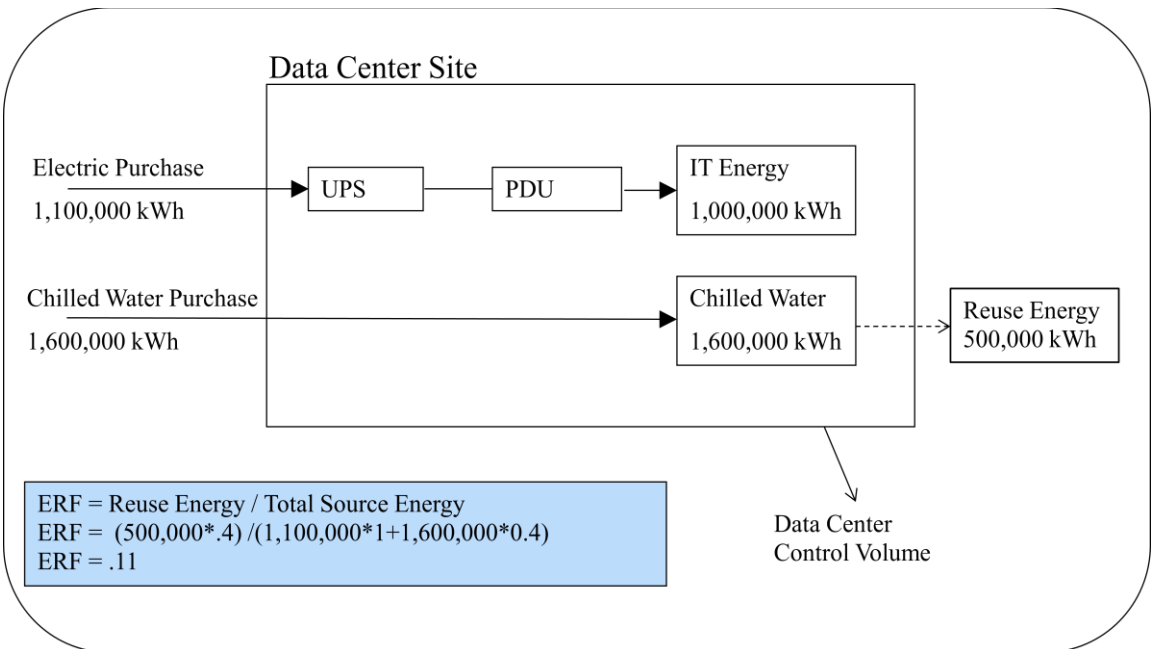
To compute ERF, any energy used by the data center that leaves the control volume for use elsewhere, is considered Reuse Energy. In Example K, the Reuse energy is denoted by (G), and should not be confused with the reject energy (I). Total energy consumed by the data center is identical to total energy 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

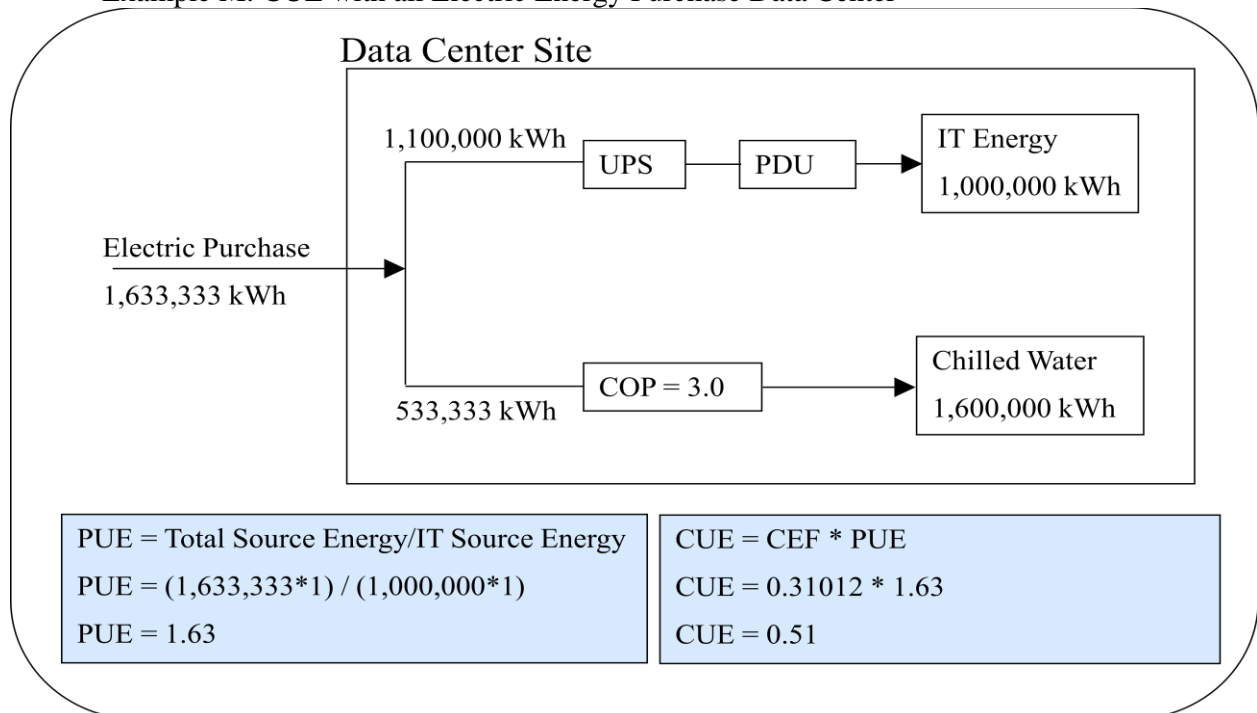
The units of the CUE metric are kilograms of carbon dioxide emission equivalents (kgCO₂eq) per kilowatt-hour (kWh) of IT energy consumption. CUE has an ideal value of 0.0, indicating that no carbon use is associated with the data center’s operations.

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



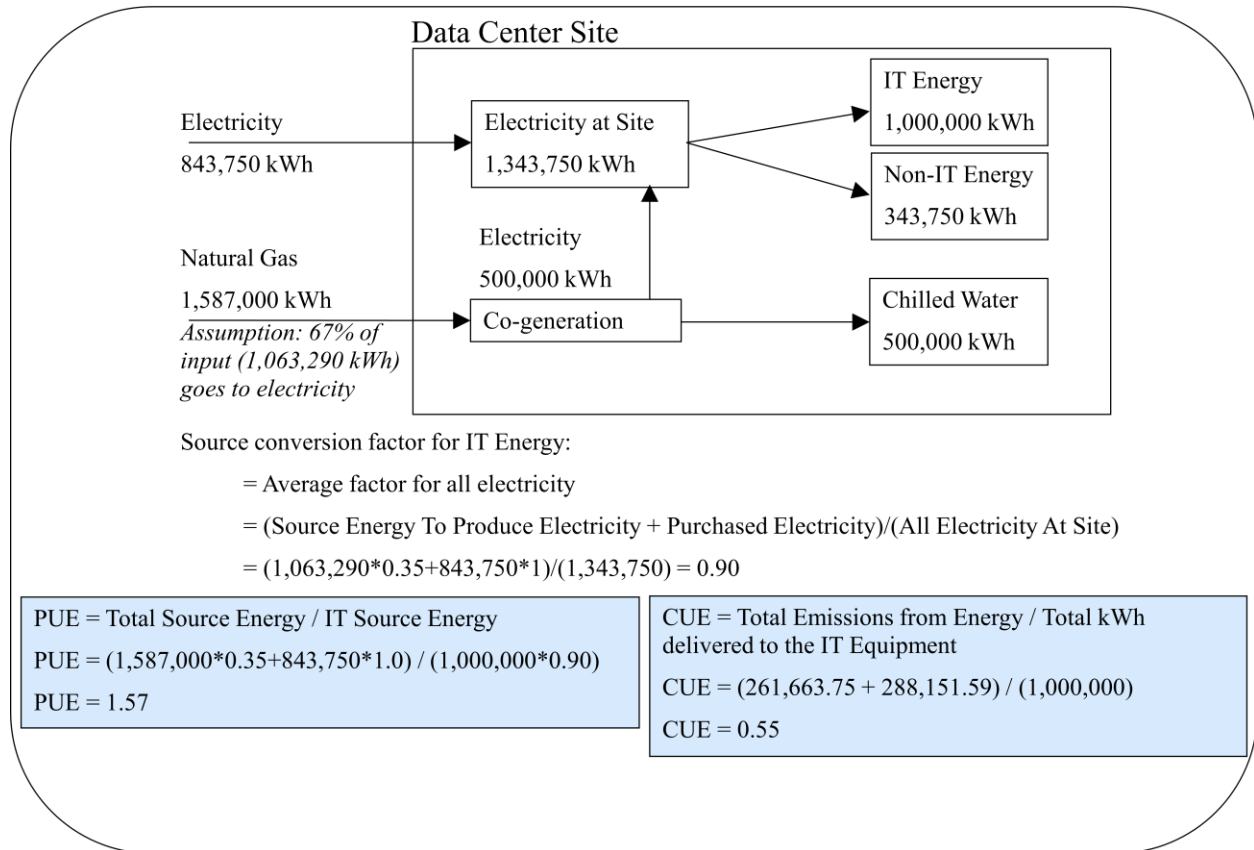
CEF and CUE:

- 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.

【仮訳】 Appendix F—総合的な評価体系

総合的な評価体系によって、多数の効率指標と紐づくデータセンタの改善への認識を深めることができる。例えば、ある特定の指標の改善に絞った特定の対策を実施すると、他の指標が悪くなってしまう可能性がある。総合的な評価体系によって、データセンタ事業者はすべての指標を同時に俯瞰することができるようになる。

期待される成果の節では、データセンタのエネルギー効率（もしくは炭素排出削減）の3つの側面を示した。総合的な評価体系は、データセンタの複数のエネルギー効率指標をひとまとめにして認識する手段である。

成果(1.a) – IT 機器について： IT 機器の定格エネルギー消費量に対する仕事能力を測定する。また、IT 機器利用率を測定する。

成果(1.b) – データセンタの設備とインフラについて： データセンタのインフラ（付帯設備）の効率（PUE = Power Usage Effectiveness）を測定する。

成果(2) – 炭素排出量削減のため、再生可能エネルギーと再利用エネルギーの量を測定する。

データセンタのエネルギー効率と温室効果ガスの排出を理解し改善するためには、これらの観点すべてをひとつの図でみるのが有用である。図1のようなスパイダーチャート（またはレーダーチャート）は、総合的な評価体系において様々な指標を見るひとつの手法である。スパイダーチャート（レーダーチャート）では、期待される成果(1.a) (1.b) (2)すべての指標が各軸に割り当てられ、データセンタ全体のエネルギー効率を評価することができる。

総合的な評価体系では、期待される成果[上記の(1.a) (1.b) (2)]のそれぞれから最低一つ以上の指標がスパイダーチャート（レーダーチャート）に採用されなければいけない。現時点ではタスクフォースは期待される成果 1.a の推奨指標は提供していない。合意に達し推奨指標が提供された際には、その指標が総合的な評価体系に含められるべきである。指標（軸）の数はデータセンタ事業者が選択する指標によって異なってくるかもしれない。図2と図3はそれぞれ4つの軸、5つの軸のスパイダーチャート（レーダーチャート）例を示している。図2では成果 1.a に対し2つの指標が採用されている。図3では3つの指標が成果2に採用されている。これらの指標は成果 1.a と成果2のそれぞれ別の側面を評価している。事業者は、指標を選択したら次にそれぞれの軸の最小値と最大値を特定する必要がある。場合によっては、理論上の最大値と最小値が存在する（例：GECは0.0から1.0の範囲のみである）。また、明白な最大値がない場合も存在する（例：PUEには最大値がない）。よって軸の最大値は目標値または他の見積もりに基づき定めなければならない。指標の最小値と最大値の選択は、指標間の潜在的な重みづけとなりうることから、これらの過程には注意が必要である。

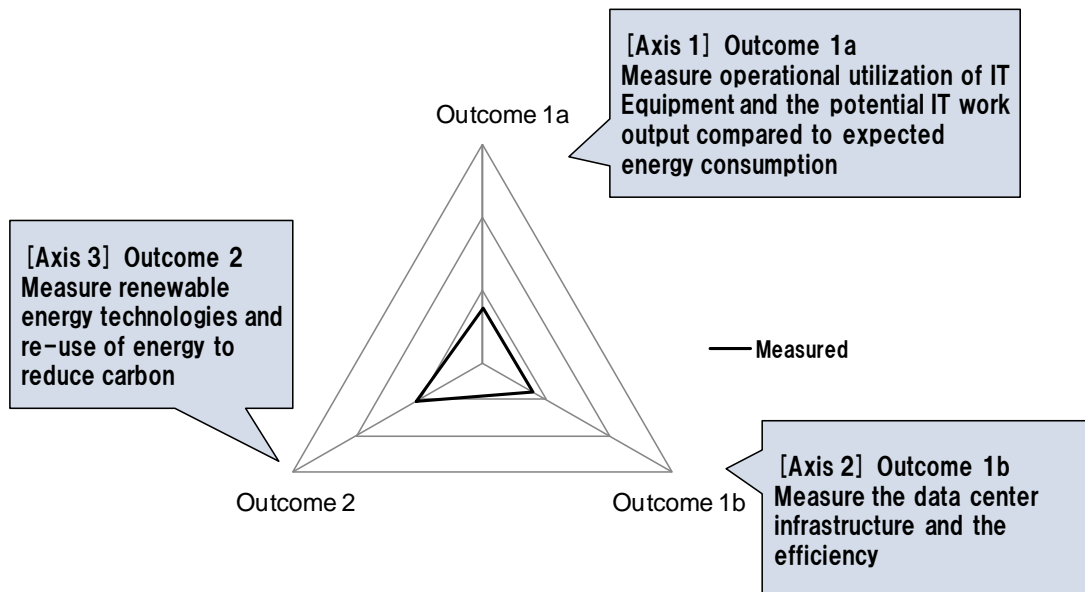


Figure 1: A possible expression of “Holistic Framework”

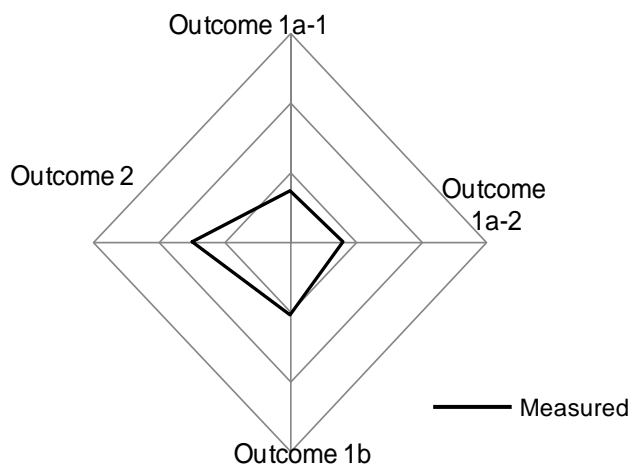


Figure 2: Possible variations of a spider chart expression

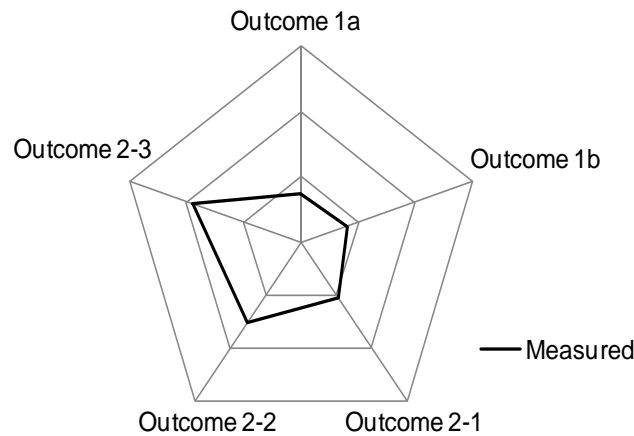


Figure 3: Possible variations of a spider chart expression

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.

【仮訳】すべての指標を統合的に可視化するスパイダーチャート（レーダーチャート）を利用することには、いくつかの利点がある。データセンタ事業者は、スパイダーチャート（レーダーチャート）を見ることによって、最も悪い指標がどれかを判別できる。そして、それは最も改善が必要な領域を示す可能性がある。さらに、事業者は、スパイダーチャート（レーダーチャート）によって、すべての指標の効率改善効果を可視化することができる。目標は、効率向上に向けた方向へすべての指標を動かすことである。よって、データセンタの改良後にスパイダーチャート（レーダーチャート）を見直し、すべての指標が改善されていることを確認することが重要である。最後に、スパイダーチャート（レーダーチャート）には現在の実測値だけでなく目標値も表示できる。そこで、目標達成に向けた変化を、全ての指標について同時に追跡することも可能である。