

# Estimating a Data Center's Electrical Carbon Footprint

## White Paper 66

Revision 0

by Dennis Bouley

### > Executive summary

Data center carbon emissions are a growing global concern. The U.S. Environmental Protection Agency (EPA) cites data centers as a major source of energy consumption in the United States. The EPA has set an efficiency target for government data centers: a 20% reduction in carbon footprint by 2011. European Union (EU) members have agreed to cut their combined emissions of greenhouse gases to 8% below the 1990 level by 2012. Data center owners will be increasingly challenged to report their carbon emissions. This paper introduces a simple approach, supported by free web-based tools, for estimating the carbon footprint of a data center anywhere in the world.

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## Introduction

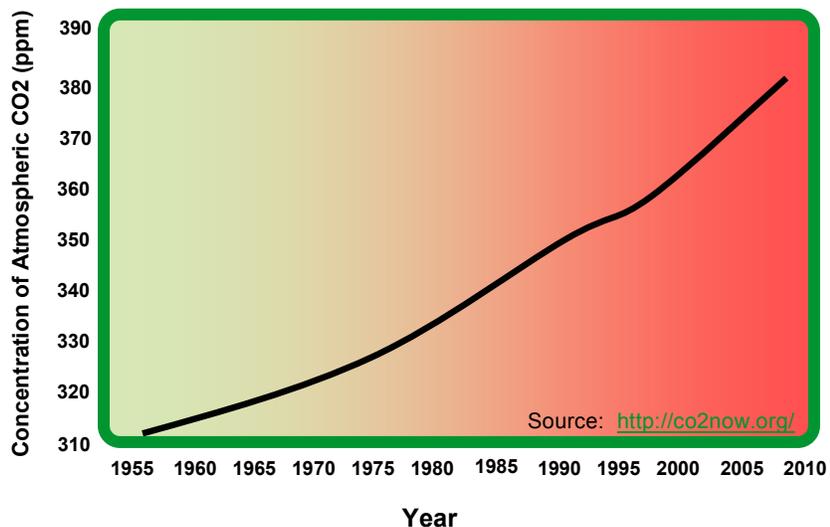
Carbon and energy issues appear in international headlines with increased frequency. Governments, non-profit organizations, and corporations now conduct studies to analyze their carbon footprint on a regular basis. Their goal is to measure the impact of their activities on global warming and to establish action plans that reduce carbon emissions.

According to a U.S. Environmental Protection Agency (EPA) report, US data centers consumed 61 billion kilowatt-hours of power in 2006. That's 1.5% of all power consumed in the United States and represents a cost of \$4.5 billion. Data centers have been identified as one of the fastest growing consumers of energy. The EPA is mandating that government agencies develop strategies for energy efficiency in government-operated data centers with a target of 20% improvement by 2011<sup>1</sup>, and private sector data centers may soon be asked to meet mandated CO<sub>2</sub> limits.

The 15 countries that were EU members before 2004 have committed to the principles of the Kyoto Protocol. They have agreed to cut their combined emissions of greenhouse gases to 8% below the 1990 level by 2012<sup>2</sup>. In addition, The European Commission (EC) Code of Conduct on Data Center Energy Efficiency, which is a set of voluntary efficiency measures, has been established to set minimum standards that will serve as a basis for more stringent regulation in the future. The ultimate goal is to improve average data center efficiency by 30%.

**Figure 1**

*Growth of worldwide atmospheric CO<sub>2</sub>*



In 2007, data centers in Western Europe consumed a whopping 56 terawatt-hours (TWh) of power per year. According to the EU, this figure is likely to almost double to 104 TWh by 2020<sup>3</sup>. This projected growth, if not offset by innovations in efficient energy management, will prevent the European Union from achieving its overall carbon reduction and climate change targets. The energy consumption of data centers and how this translates into estimating a carbon footprint is the focus of this paper. **Figure 1** shows the growth of worldwide atmospheric CO<sub>2</sub>.

<sup>1</sup> US Environmental Protection Agency, Report to Congress on Server and Data Center Energy- Public Law 109-431, August 2, 2007

<sup>2</sup> European Environment Agency, Greenhouse Gas Emission Trends and Projections in Europe 2008, EEA Report No. 5, 2008

<sup>3</sup> European Commission, Code of Conduct on Data Centres Energy Efficiency - Version 1.0, October 30, 2008

How “green” is a given data center? To answer that question, data center professionals must first determine their energy usage and then convert that usage into carbon emissions. To determine whether a data center's carbon footprint is being reduced, the first step is to properly measure consumption. Three key variables have a major impact on data center power consumption: data center location, IT load, and electrical efficiency. The impact of changes to these variables can be modeled using a series of web-based APC TradeOff Tools™. These tools will be discussed later in this paper.

## Definition of key terms

When determining the environmental impact of a data center, it is important that the terms used to describe measurement outputs are understood. Below is a list of key terms used in discussions surrounding the environmental impact of data centers:

**Carbon dioxide emissions coefficient (“carbon footprint”)** This is a measurement of the amount of greenhouse gas, including carbon dioxide (CO<sub>2</sub>), caused by basic activities such as driving a vehicle or powering a utility plant. In the case of a utility plant, the measurement includes power generation plus transmission and distribution losses incurred during delivery of the electricity to its point of use. This paper defines the carbon footprint of a data center as the carbon emissions equivalent of the total amount of electricity a particular data center consumes.

The geographical location of a data center plays an important role. A data center located in an area with easy access to hydro, nuclear, or wind power, for example, would have a lower carbon footprint than a data center located in an area that depends more heavily on coal, oil, or natural gas.

**Peaker plant** Utility companies address peaks in their electricity demand by running auxiliary power generation plants called “peaker” plants. These plants are coal-fired, resulting in high CO<sub>2</sub> emissions. Depending upon the condition of the region's electrical grid, peaker plants may operate many hours a day or only a few hours per year. The utility relies on these older, less efficient plants to provide power when demand is at its peak – for example, late afternoon and early evening on a hot summer day when businesses are still open and when people in homes are arriving from work and preparing dinner. Peaker plants, if they are significant in the geographical area of the data center, affect the “avoided emissions” output of the *Data Center Carbon Calculator* tool (discussed later in this paper).

**Avoided emissions** When reductions are made to a data center's electrical consumption, the demand on utility power is lower, therefore avoiding carbon emissions and reducing carbon footprint. If the power reduction lowers the utility's use of peaker plants, the avoided emissions are magnified. “Avoided emissions” is one of the selectable outputs in the *Data Center Carbon Calculator* tool discussed later in this paper. It is a more accurate indicator of carbon benefit than “carbon footprint” if peaker plants are a significant component of power supply in the geographical area of the data center.

**CO<sub>2</sub> (carbon dioxide, or “carbon”)** CO<sub>2</sub> is the gas that contributes the most to the planetary greenhouse effect, making up 76% of the greenhouse gases in our atmosphere<sup>4</sup>. CO<sub>2</sub> is emitted into the atmosphere in large amounts and has a lifecycle of approximately 100 years. From an overall data center lifecycle perspective, the general term “carbon emissions” includes CO<sub>2</sub> emitted during the manufacturing process of all the components that populate a data center (servers, UPS, building shell, cooling, etc.). This aspect of carbon emissions can be termed “embedded carbon”. The term carbon emissions also includes CO<sub>2</sub> emitted during the operation of the data center (in terms of electricity consumed), the maintenance of the data center (i.e. replacement of consumables like batteries, capacitors, etc.), and the disposal

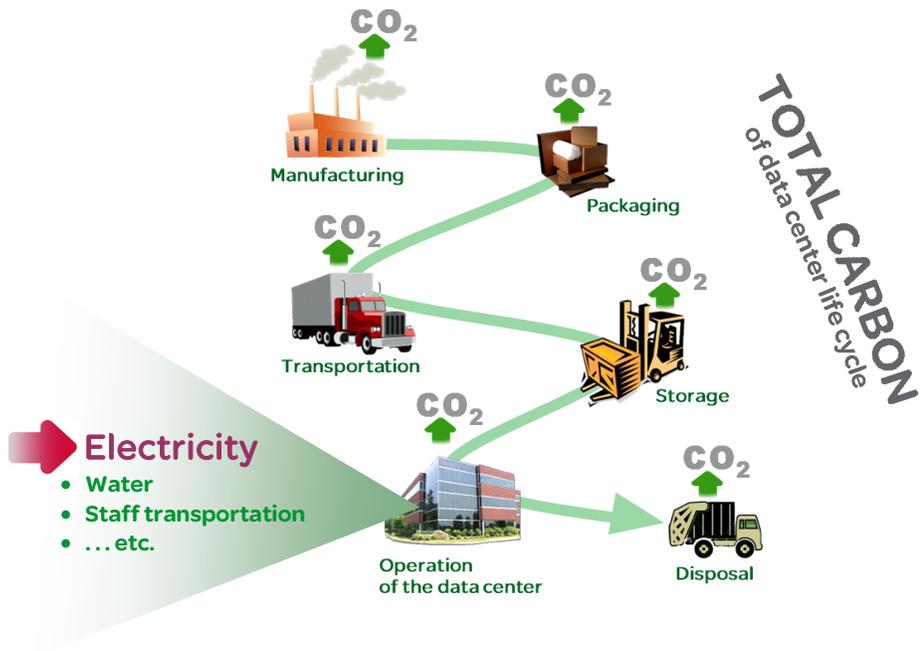
<sup>4</sup> Intergovernmental Panel on Climate Change, *Fourth Assessment Report*, 2007

of the components of the data center at the end of the lifecycle (see **Figure 2**). The focus of this paper – and the tools described later – is CO<sub>2</sub> emissions related to the energy consumption of the data center during operation.

**Figure 2**

Carbon-producing phases of the product life cycle of a data center

The subject of this paper is the **electrical consumption** of data center operation



## Data center total carbon profile

This paper focuses on estimation of carbon emissions from the operating energy consumption of a data center – which can be calculated using the tools described later – but a complete analysis would also include (1) the embedded carbon contribution from *all* phases of the product life cycle shown in **Figure 2** and (2) carbon contribution of the physical building itself, if the building is a dedicated data center structure. Estimating these is beyond the scope of this paper, but here is a brief look at the total picture:

### > The data center

Quantified for a 1MW data center

<b>Electricity</b>	177,000,000 kW-hr
<b>Water</b>	60,000,000 gal (227,000,000 l)
<b>Copper</b>	145,000 lbs (65,771 kg)
<b>Lead</b>	21,000 lbs (9,525 kg)
<b>Plastic</b>	33,000 lbs (14,968 kg)
<b>Aluminum</b>	73,000 lbs (33,112 kg)
<b>Solder</b>	12,000 lbs (5,443 kg)
<b>Steel</b>	377,000 lbs (171,004 kg)

Assumptions: 10-year lifetime, high redundancy, two IT refreshes, includes power/cooling/racks/IT, does not include the building

### > The building “shell”

Quantified for a 1MW data center

<b>Concrete</b>	
<b>Masonry</b>	Brick, stone, grout
<b>Metals</b>	Steel beams, lead pipes, copper wires, aluminum sheet metal, stairs, railings, floor plates, grates, nails, screws, bolts, aluminum flashing, sheet metal, aluminum ventilation, louver systems
<b>Wood, plastic, composite</b>	Room framing, wire coatings, doors, windows
<b>Thermal/moisture protection</b>	Insulation, vapor barriers
<b>Water</b>	Cleaning, cooling, fire suppression
<b>Chemicals</b>	Glue, glycol, cleaners, water repellants sealants, fire suppression
<b>Glass</b>	
<b>Tar</b>	Roofs, roads, sidewalks, parking lots
<b>Shingles, tiles</b>	

How do all of these materials break out, in terms of carbon emissions contribution, when constructing a typical facility? **Table 1**<sup>5</sup> provides a glimpse of the basic materials that go into the construction of a building “shell”.

**Table 1**

*Breakdown of embedded CO<sub>2</sub> in building materials*

Materials - building shell 5,700 ft <sup>2</sup> (530 m <sup>2</sup> ) office facility	Tonnes of CO <sub>2</sub>	Percentage of total
Foundation (concrete)	4.7	4%
Flooring (concrete slab, insulation)	39.9	31%
Ceilings (plaster board)	2.3	2%
Structure (steel beams)	15.4	12%
External walls (brick, insulation)	32.1	25%
Internal walls (wood frame and plasterboard)	8.7	7%
Stairs (concrete)	1.1	1%
Windows (glass and frame)	0.59	0.4%
Internal doors (particle board)*	-0.4	-0.3%
External doors (plastic)	0.6	0.5%
Roof (wood, concrete, insulation)	23.4	18%
<b>TOTAL</b>	<b>128.3</b>	<b>100%</b>

\* This negative number actually has a *positive* impact on CO<sub>2</sub> emissions (i.e., goes beyond neutralizing CO<sub>2</sub> emissions) because it uses recycled materials

### How do office buildings compare to data centers?

Commercial office buildings and data centers consume energy in different ways. A data center is energy intensive; it requires a high level power and cooling compared to an office building. This means that the materials used to construct a typical office building represent a greater percentage of the carbon emissions pie because the office building is lower in energy intensity.

In fact, data centers can be 40 times as energy intensive as an office building. Therefore, data centers more closely resemble industrial facilities than office buildings. Data centers are also designed for computers, not people; most have no windows and minimum circulation of fresh air. Office buildings also operate on very different time lines (50-year life cycle) compared to data centers (10-year life cycle). **Figure 3**<sup>6,7</sup> compares energy use profiles for both buildings and data centers.

<sup>5</sup> Edinburgh Centre for Carbon Management Ltd., Forestry Commission Scotland Greenhouse Gas Emissions Comparison Carbon Benefits of Timber in Construction, August 2006

<sup>6</sup> LBNL 53483, High Performance Data Centers, William Tschudi, Teng Fung Xu, Dale Sartor, Jay Stein, March 30, 2004

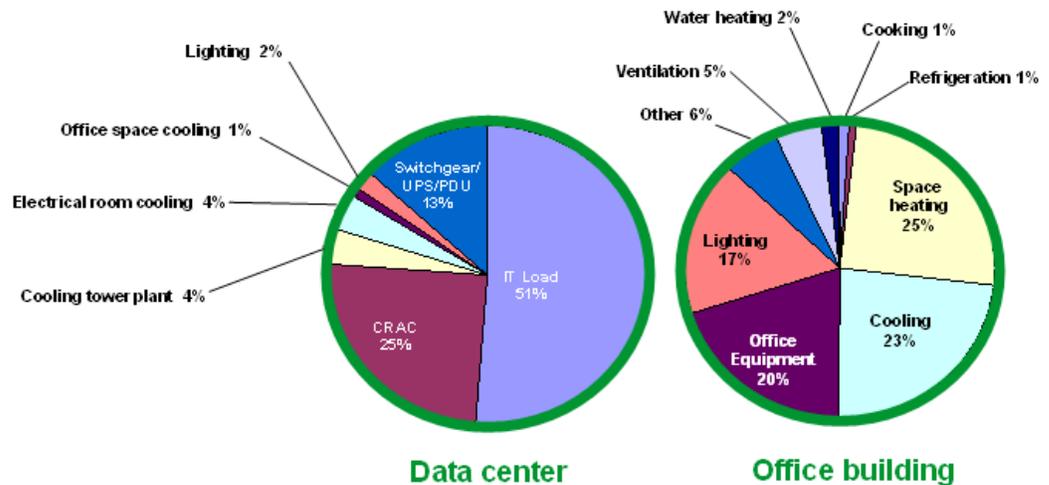
<sup>7</sup> <http://www.epa.gov/RDEE/documents/sector-meeting/4bi-officebuilding.pdf> (adapted from E Source 2006)

### Embedded carbon

Note that the figures in **Table 1** include the CO<sub>2</sub> - producing processes that occur in order for all the material and equipment to be manufactured, delivered, and disposed of – called “embedded carbon”.

In the case of a new server for a data center, the imbedded carbon from the server’s manufacturing and delivery process would add to the carbon footprint of the data center hosting that particular server (this includes water consumption (for cooling), electrical consumption, smokestack operation (of raw materials suppliers) and employee transportation (drives and flights related to the business). The employee transportation number alone could be significant. Consider a large organization with 100,000 employees, 50% of which average two flights per year. Assume .33 tonnes of carbon footprint per round trip flight (e.g., London to New York and back)<sup>8</sup>. That would represent an annual CO<sub>2</sub> emission of 33,000 tonnes (100,000 flights x .33 tonnes per flight). In addition, all of the servers and related data center equipment contribute to the CO<sub>2</sub> number during operation.

Organizations and governments concerned with global warming are proposing that all corporations be assigned a carbon allocation. Under such an allocation plan, exceeding the allocation would result in fines and other penalties. The concept of carbon credits, and the ability to trade carbon credits, is also being introduced in many parts of the globe (e.g., planting trees on or around the premises of the data center site to reduce carbon footprint). This global carbon footprint measurement would account for all processes and purchases within an organization. **Figure 3** compares the energy profiles of a typical office building and data center.<sup>9</sup>



**Figure 3**  
Energy consumption profile comparison of data center and office building

### The impact of power generation

To understand the impact of the data center electrical consumption on carbon footprint, it is important to understand how a utility is tasked with supplying energy. Energy-related carbon dioxide emissions account for 60% of global carbon dioxide emissions (and an average of 80% in most developed countries). The utility, which generates various forms of raw power into electricity, is rarely one monolithic entity. Utilities generate their power from several sources: coal, natural gas, oil, nuclear reactor, hydroelectric, tides, and wind farms.

<sup>8</sup> The Edinburgh Centre for Carbon Management, *Estimates of Emissions for Selected Items and Activities*, ECCM technical document #4, October, 2000

<sup>9</sup> The cooling system represented in **Figure 3** is a CRAC, DX-based system with a cooling tower. Chilled water and dry-cooler systems have a similar total cooling load, but have a different breakdown of CRAC, chiller, and tower loads.

The “mix” or “profile” of energy sources that the utility employs to fuel generation of electricity is important in calculating a data center's carbon footprint. Fossil fuels, the biggest offenders when it comes to CO<sub>2</sub> emissions (see **Table 2**), still account for most of the world's energy supply (82% in 2007). The type of fossil fuel burned by the utility also plays a major role. Although coal represented only 26% of the total primary energy supply in 2007, it accounted for 42% of global CO<sub>2</sub> emissions (see **Table 2**)<sup>10</sup>. Coal has heavy carbon content per unit of energy released. Compared to natural gas, coal is, on average, nearly twice as energy intensive.

Also, when a data center purchases a given unit of power from a utility, three times the amount of carbon is produced during the process of converting the fuel into electricity and delivering the electricity to the site.

**Table 2**

*Global primary energy sources and corresponding CO<sub>2</sub> emissions*

Fuel type	Percentage of global primary energy supply	Percentage of global CO <sub>2</sub> emissions
Oil	34%	38%
Coal	26%	42%
Natural gas	21%	20%
Other*	19%	0%

\*Includes nuclear, hydro, geothermal, solar, tide, wind, combustible renewables, and waste

Electricity generation is one of the three principal sources of greenhouse gas emissions (autos/transportation and deforestation/agriculture are the other two). One of the biggest challenges faced when attempting to reduce a data center's electrical consumption (greenhouse gas emissions) is to link data center activities to electricity use. A data center consumes electricity when IT and physical infrastructure loads are using power to process information or when elaborate cooling systems remove heat from the data center to keep temperatures stable.

The fuel or energy source used to generate electricity is the most significant factor affecting the year-to-year changes in CO<sub>2</sub> emissions. Because hydroelectric and nuclear generation displaces fossil-fueled generation when available, CO<sub>2</sub> emissions increase when hydroelectric or nuclear power is unavailable and fossil-fueled generation is used as a replacement. Conversely, CO<sub>2</sub> emissions can be reduced through a greater use of nuclear, hydroelectric, and renewable energy for electricity generation<sup>11</sup>.

## How data center energy use relates to carbon emissions

Three key factors affect the carbon footprint of a data center:

1. Location
2. IT load
3. Electrical efficiency

<sup>10</sup> International Energy Agency, *CO<sub>2</sub> Emissions from Fuel Combustion Highlights*, 2009 edition

<sup>11</sup> Department of Energy / Environmental Protection Agency, *Carbon Dioxide Emissions from the Generation of Electric Power in the United States*, July 2000

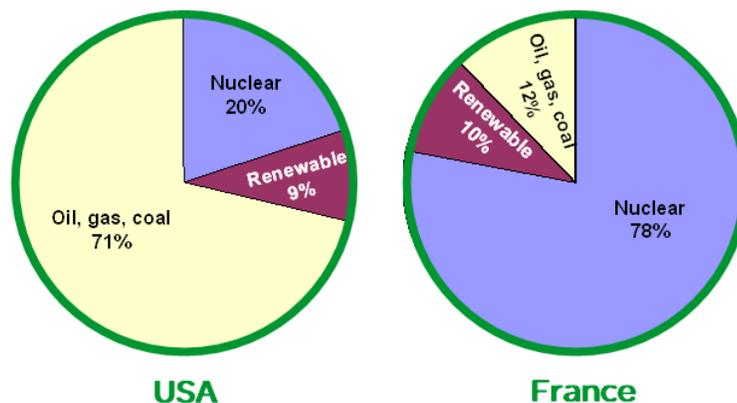
## First key factor: Location

Weather variables such as outdoor temperatures and humidity levels are an influencing factor on energy consumption. A geographical location which experiences extreme temperatures and humidity levels will consume more energy as the data center physical infrastructure systems work harder to maintain consistent, moderate temperature and humidity levels.

The local source of power generation will also have a major impact on a data center's carbon footprint (see **Figure 4**)<sup>12</sup>. In France, for example, most of utility generated power comes from nuclear energy. A data center in France would have a much lower carbon footprint, from a daily operations perspective, than one located in the Midwestern US. In the case of the US data center, the energy source "mix" may be 60% coal, 20% oil, 10% natural gas and 5% hydro and 5% wind farms. The data center in central France would draw 95% of its electricity from a nuclear power plant. A nuclear reactor does not emit CO<sub>2</sub>. A coal burning plant does emit CO<sub>2</sub>.

**Figure 4**

Electricity generation by fuel type: USA vs. France



The uniqueness of a data center's location also will impact the frequency of "avoided emissions" that the site can leverage. Avoided emissions reflect the average activity of peaker plants in the local utility's network. A closer look at the peaker plant phenomenon reveals that when consumption decreases, peaker plant generation is turned down (or turned off). Avoided emissions come into play only when fossil-fired generation plants are involved. Peaker plants are typically older, more inefficient facilities. Most peaker plants have been replaced by cleaner, more efficient plants but are kept operational just in case electricity demand requires that they be turned on.

Typical peak hours are during weekday mornings and late afternoon or early evenings. These are times when many workplaces are still open and when people return home from work, start cooking dinner, and turn up the air conditioning or turn up the heat, depending upon geographical location and the time of year. These times are when peaker plants would likely be engaged and when local data center carbon footprint would increase (see **Figure 5**).

## Second key factor: IT load

IT load reflects how much power the IT equipment in the data center consumes. The IT load consists of all of the IT hardware components that make up the IT business architecture: servers, routers, computers, storage devices, telecommunications equipment, as well as the security systems, fire and monitoring systems that protect them. Loads can go up (an increase in processing requirements from the lines of business) or down (impact of virtualiza-

<sup>12</sup> <http://www.getenergyactive.org/fuel/mix.htm> - accessed February 8, 2010

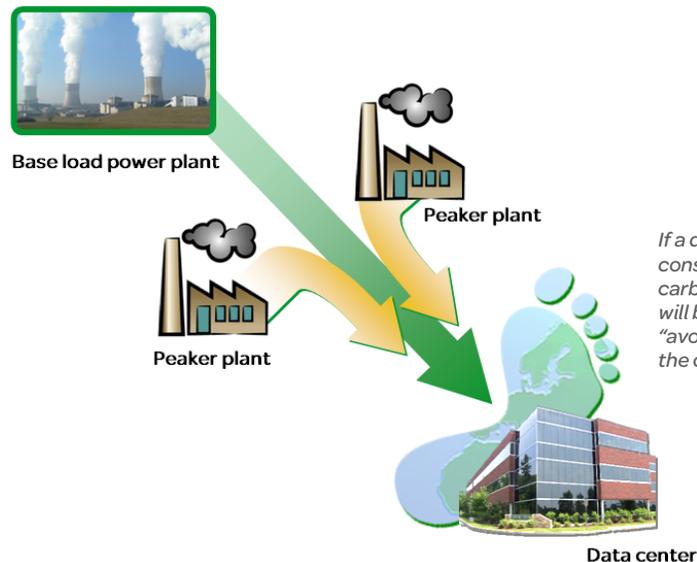
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tion or consolidation). The higher the load, the more power will be required to keep it up and running and the higher the carbon footprint.

### Third key factor: Electrical efficiency

Unfortunately, the traditional practice in data centers of oversizing the physical infrastructure to support the IT load has a very negative impact overall data center efficiency and therefore impacts carbon footprint. Data centers are oversized in order to build in a fat margin for error in terms of estimating data center capacity. Oversizing results in underutilization of equipment (such as servers that are plugged in 24 hours a day but that are very rarely used). Fortunately, new generations of modular scalable IT and physical infrastructure equipment allow for a “pay as you grow” philosophy that helps to optimize equipment utilization. In addition, advancements in capacity planning software allow for much more accurate prediction of data center capacities and of data center power consumption.

A number of factors in a data center can bring efficiency up or down. Everything from the broad design of the data center (server row orientation, power architecture, cooling architecture, server design, level of redundancy, IT load, etc.) to the deployment of specific technologies (UPS, chillers, economizers) impacts efficiency. For more information on how to manage factors that affect data center efficiency, refer the APC white papers listed at the end of this paper.



**Figure 5**

Peaker plant operation adds to the electrical portion of a data center's carbon footprint

*If a data center's electrical consumption is REDUCED, high-carbon peaker plant contribution will be reduced, which increases "avoided emissions" and reduces the carbon footprint*

## Tools for estimation of electrical carbon footprint

Automated tools such as the APC Data Center Carbon Calculator, Data Center Efficiency Calculator, IT Carbon & Energy Allocation Calculator, and Data Center Power Sizing Calculator TradeOff Tools™ can help data center professionals understand how they use electricity, and to recognize how changes in efficiency can impact carbon footprint. These tools do not consider embedded carbon – the emissions from power used to manufacture, deliver, and dispose of equipment and materials used in the data center and in the construction of the building that contains it.

Using these web-based tools, you can quickly arrive at an estimated carbon footprint for your data center. All four of the tools are designed in the same standardized format with inputs on the left and outputs on the right.

 Click on icon  
to link to live tool



## Data Center Power Sizing Calculator

The *Data Center Power Sizing Calculator* defines basic characteristics of the IT load and calculates how much utility power would be required to support that load. The interactive nature of the tool allows the user to experiment with “what if” scenarios by modifying the load characteristics of servers, mainframes, and storage. Total load is then calculated and the tool generates a corresponding utility power requirement



## Data Center Efficiency Calculator

The *Data Center Efficiency Calculator* profiles a data center and calculates the resulting efficiency and electrical cost based on key characteristics of the data center. The user inputs details of the power and cooling infrastructure, and results are calculated based on a tested and validated four-parameter efficiency model.



## IT Carbon & Energy Allocation Calculator

This tool allocates carbon emission and energy costs to data center users. The goal is to make users aware of the energy costs they incur and to encourage them to pursue energy saving approaches such as virtualization and server retirement. For more information on methodologies for data center user energy chargeback, see APC White Paper 161, *Allocating Data Center Energy Costs and Carbon to IT Users*.

 Related resource  
**APC White Paper 161**

*Comparing UPS System  
Design Configurations*



## Data Center Carbon Calculator

The *Data Center Carbon Calculator* tool calculates the “green” characteristic of a data center by converting energy usage rates into carbon emissions. This tool shows how hypothetical changes to a data center's location, efficiency, and IT load affect carbon dioxide emissions and the electric bill.

The inputs to the carbon calculator are straightforward:

- Physical infrastructure details for two scenarios – before and after
- IT load – before and after
- Geographical location of the data center

The total kilowatt-hours consumed are computed based on DCiE/PUE and IT loads, multiplied by the carbon emissions rate for electricity in the geographical location, then converted to car equivalents. No specific data needs to be collected onsite, other than what would already be collected to measure or compute DCiE/PUE.

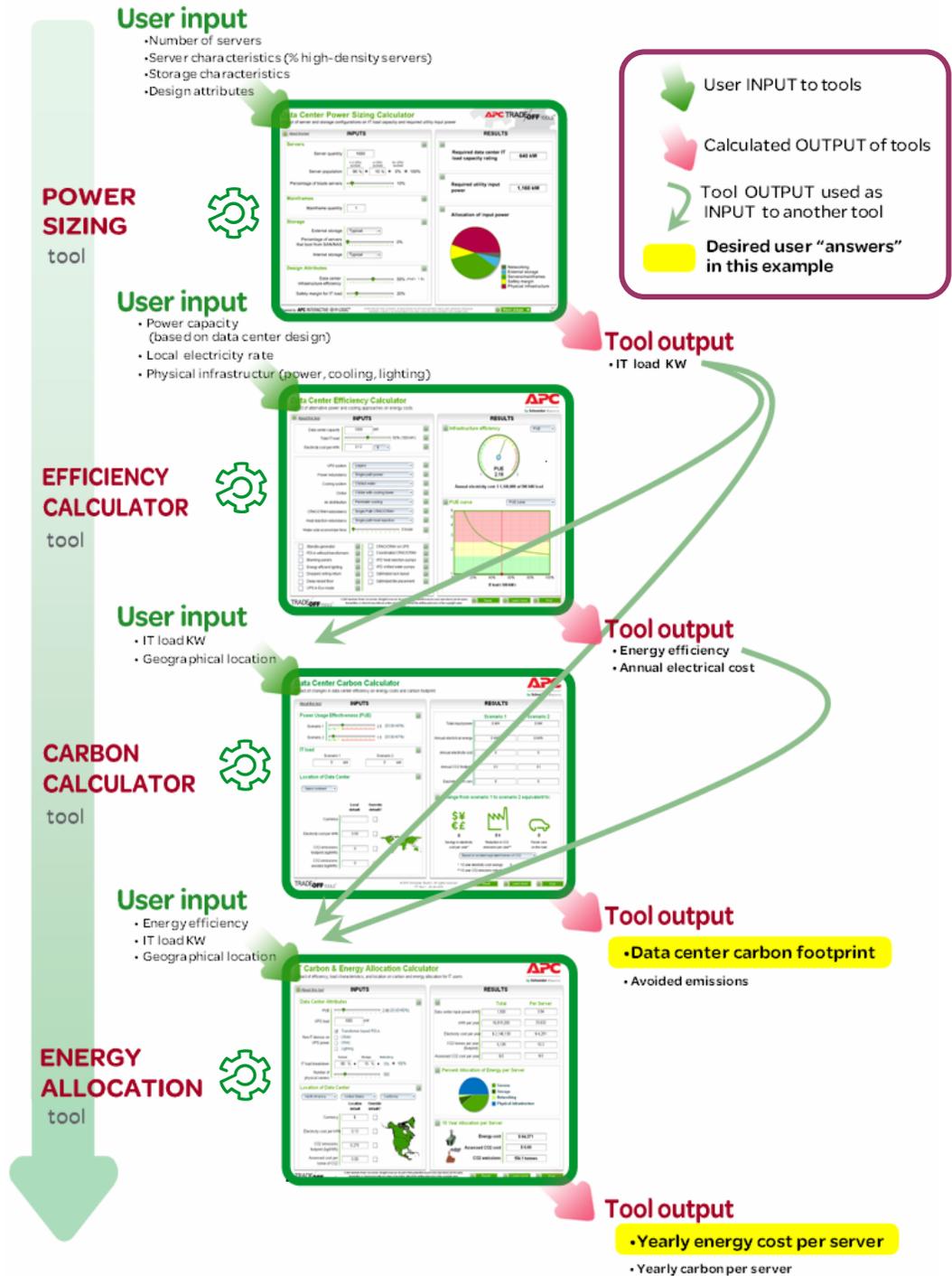
For computation of carbon emissions, state and country data are taken from an EIA report (Energy Administration Information, Unites States)<sup>13</sup>. For the car equivalent, 4.5 tonnes of CO<sub>2</sub> per year are assumed, which is a figure published by the EPA.

These four tools work together – the output from one can be used as input to another. Although all four tools can be used in conjunction with each other, you might only require a subset of the tools, depending on how much data you already have. If you already know the IT load, for example, there is no need for the power sizing calculator. If you already have your PUE number, there is no need for the efficiency calculator (unless performing a rough validation of the original PUE number).

<sup>13</sup> Carbon emissions data in the carbon calculator are derived from the US Department of Energy document, “*Voluntary Reporting of Greenhouse Gases*” (Appendix F - Electricity Emission Factors, 2007). [http://www.eia.doe.gov/oiaf/1605/pdf/Appendix%20F\\_r071023.pdf](http://www.eia.doe.gov/oiaf/1605/pdf/Appendix%20F_r071023.pdf) accessed December 2009

For example: You want to estimate the carbon footprint of the data center's annual energy consumption and generate a projected cost for a particular group of users. By using the TradeOff Tools, you could proceed as in **Figure 6**.

 Click on icon to link to live tool

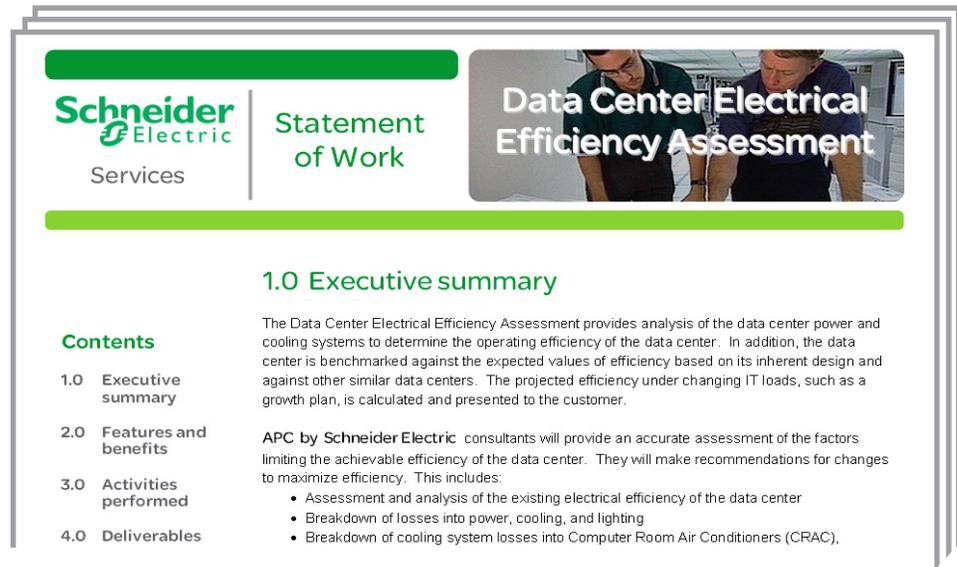


**Figure 6**  
Sample sequence of tools to calculate carbon footprint and yearly per-server energy cost

Together these tools provide the data and calculations to arrive at an estimate of efficiency and carbon footprint. Entering the data into each of the tools requires some knowledge about the particular data center's environment (e.g., number of servers, type of cooling systems, power distribution). In some cases, IT staff and facilities staff will work together to gather appropriate input data. Third parties, such as APC, can provide assistance by offering data center efficiency assessments that can also provide valuable input to the tools (**Figure 7**).

**Figure 7**

*An electrical efficiency assessment can establish your data center's actual measured energy metrics for accurate input to energy analysis tools*



## Conclusion

Data center owners – for political, social, or economic reasons – are under pressure to reduce the energy consumption of their data centers. Many data centers built today have not yet pursued any serious attempts to control their energy consumption. Traditional power and cooling systems are inefficient, stranded capacity rates are high, and server utilization is low. Therefore, the carbon footprints of data centers are significantly higher than they need to be.

Part of the solution lies with the providers of energy. The redesign of national and international power grids is needed so that inefficient fossil-fueled plants can be either modified or phased out. But the users of energy have an equally important role in improving electrical efficiency. Data centers can begin by “rightsizing” their power and cooling infrastructure so that the actual IT load operates closer to full load capacity.

The intermediaries between suppliers and users – companies like Schneider Electric – can also contribute, by providing high efficiency solutions to data centers, buildings, and homes and providing tools to help users effectively manage their energy.

Energy efficiency is a long-term worldwide initiative that involves efforts from all parties. Tools such as APC’s power sizing, efficiency, carbon, and carbon allocation calculators are a step towards confronting the energy challenge.



### About the author

**Dennis Bouley** is a Senior Research Analyst at APC by Schneider Electric's Data Center Science Center. He holds bachelor's degrees in journalism and French from the University of Rhode Island and holds the Certificat Annuel from the Sorbonne in Paris, France. He has published multiple articles in global journals focused on data center IT and physical infrastructure environments and has authored several white papers for The Green Grid.



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