Google Apps: Energy Efficiency in the Cloud

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Executive Summary

We know that cloud-based computing can reduce IT capital costs, reduce labor costs, and enhance productivity. And a growing body of evidence shows the cloud is also remarkably efficient.[1] Last year we released a paper on the energy savings from using Gmail instead of locally hosted email.[2] Here, we expand on that analysis to include the cloud-based office applications of Google Apps. Our estimates, which we've supported with a case study from a Google Apps client, show that migrating basic IT applications to Google Apps significantly reduces energy consumption and carbon emissions.

Based on our analysis, a typical company or organization that migrates to the cloud could:

- save an estimated 68–87% in energy for its office computing
- reduce similar amounts of carbon emissions

These findings are consistent with a case study presented in this paper of the actual savings achieved by the U.S. General Services Administration (GSA), a Google Apps client with approximately 17,000 users. By switching to Google Apps, GSA reduced server energy consumption by nearly 90% and carbon emissions by 85%. We estimate the cost savings from this reduction in energy use will be $285,000 annually (a 93% reduction).

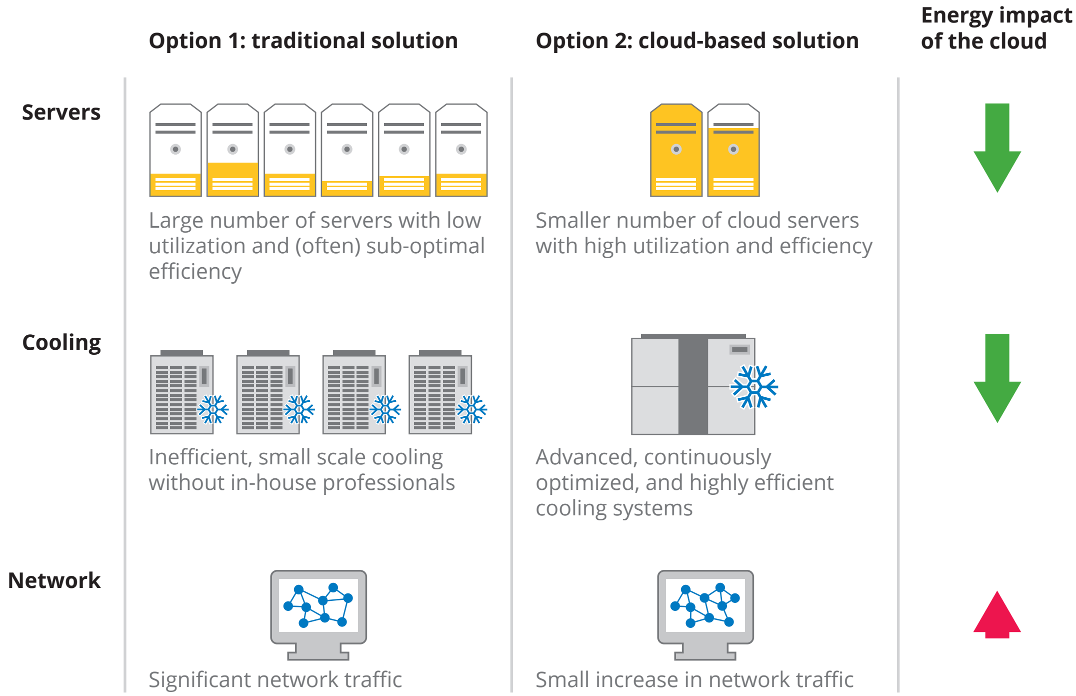
Background: the cloud-based services that we analyzed

While cloud computing can support a virtually unlimited set of applications, this analysis is focused on a subset: the basic office productivity tasks that Google Enterprise supports from the cloud. Google Enterprise[3] is a suite of services that includes:

- Google Apps – Familiar web-based applications including email, calendaring, spreadsheets, documents, and other applications
- Vault services – Solutions for mail security, archiving, and encryption
- Enterprise Search – Google-powered search for your website or intranet
- Earth and Maps – Tools to visually display your organization's information
- Chromebooks – Fast, lightweight computers designed to deliver the power of the web

For concreteness, in this paper we focus on the benefits of Google Apps. Most companies host these applications locally today. Dedicated servers on a company's internal network handle email, for example, while employees' computers run standard office applications like word processing. When a company migrates to Google Apps, shared resources in Google's data centers do the "number crunching" associated with these basic tasks. This lets companies run fewer servers, which can lead to potentially large energy and pollution savings.

Why is the cloud more energy efficient?



The chart above compares the energy needed to support two models of office computing: the standard model and the cloud-based model enabled by Google Apps. Migration to Google Apps affects energy consumption in three ways:

1. **Reduces direct energy for servers by 70–90%.**[4] Operations now require far fewer servers—and Google's servers are more fully loaded and significantly more efficient. A company that hosts its own IT services must have redundancy to guard against failure and excess server capacity to handle spiky demand. This can result in many times more servers than needed and it's common for companies to have server utilizations of 10% or less.[5] Because servers draw nearly the same amount of energy regardless of how busy they are, this results in a large waste of energy. Google is able to substantially increase utilization by aggregating demand across thousands of customers. In addition, Google data centers use customized, high-efficiency servers, power supplies, and software that need significantly less energy per unit of output than the servers deployed at most customer locations.[6]
2. **Reduces energy for server cooling by 70–90%**. The direct energy consumption from servers is only part of the story. Almost every unit of energy that a server consumes ends up as heat in the building that contains it—causing air-conditioning systems to work harder than they otherwise would. In many situations (e.g., servers in closets or small rooms), each watt of direct power consumption necessitates 1.5 additional watts of cooling. Even the top tier of large corporate data centers consume ~0.5 watts of indirect power for each watt of direct power consumption. Through significant R&D investments and innovative technologies, Google's data centers need just 0.13 watts of cooling for each watt of direct power[7]—a 75–90% improvement.[8] Our calculations, which we describe in the appendix, suggest that a typical customer will see energy costs for server cooling decrease by 70–90%.
3. **Increases energy 2–3% from use of Google servers and more network traffic**. While the savings from items 1–2 are impressive, they don't (quite) come for free. Using cloud-based services results in some additional energy consumption from the use of Google servers and an increase in traffic on the Internet.[9] Our analysis suggests a net increase of 2–3% in energy consumption for office computing migrating to the cloud.

How much can you reduce energy use and pollution by migrating to the cloud?

The table below shows the net energy savings resulting from factors 1–3 outlined in the previous section. Overall, savings range from 68-87%. Please refer to the appendix for details of how these numbers were calculated.

Source of energy consumption	**Energy consumption today** (kWh per employee per year)	**Energy consumption after Google Apps** (kWh per employee per year)	Savings from switching to Google Apps
Server direct energy	18–175	2–53	70–90%
Server cooling	18–88	2–26	70–90%
Total energy consumed per user	36–263	4–79	70–90%
Additional cloud-based energy consumption (Google + networking)[10]	--	1–5	*2–3% increase*
Total required energy	**36–263**	**5–84**	**68–87%**

Savings will tend to be higher for the following segments:

- Smaller companies, which typically have very low server utilization rates and high PUEs[11]
- Companies whose digital workloads are heavily weighted towards the applications that Google Apps provides (e.g., email, calendaring, spreadsheets, documents, etc.)
- Companies that make a concerted push not just to implement Google Apps in software, but also to migrate as much as possible towards more power efficient computers (e.g., Chromebooks)

Note that we do not consider savings from switching to cloud-based client devices such as Chromebooks. With the growth of cloud based applications, these faster, lighter and less power-hungry devices could replace laptops for many users—leading to additional energy savings of 10–45% for employee computers.

A real-world case study: GSA

The U.S. General Services Administration (GSA) migrated to Google Apps in 2012, and shared detailed data about their IT equipment before and after the migration. GSA is an independent agency of the federal government that helps manage and support federal agencies. This includes managing over 8,300 owned and leased buildings and a 210,000 vehicle motor pool. The following summary tallies up every GSA server dedicated to email and collaboration across 14 locations in the continental U.S. and applies the appropriate PUEs, electricity prices, and carbon intensities for each location:

	Before Google Apps (16,742 users)	**After Google Apps** (17,671 users)	**Savings per user**
Total number of servers operated by GSA for email and collaboration	324	61	82%
Total direct power of GSA servers (kW)	163	22	87%
Annual GSA server energy consumption per user, direct and indirect (kWh/user)[12]	175	20	89%
Additional cloud-based energy consumption (Google + network) (kWh/user)[13]	--	1-5	*2–3% increase*
Annual GSA server energy costs ($)	$307,400	$22,400	93%
Annual carbon emissions from server energy (metric tonnes of CO2)	1860	290	85%

Three points stand out from these results.

1. As anticipated, by migrating to the cloud, GSA achieved significant energy savings (i.e., 89% fewer kWh and 93% reduction in costs) and reduced pollution (i.e., 85% fewer metric tonnes of CO_2), in addition to savings from reduced server purchases and maintenance. These savings are slightly higher than our estimates above for a typical organization, reflecting the fact that GSA's mix of work is well suited for a migration to Google Apps.
2. The reduction in energy consumption was larger, in percentage terms, than the reduction in number of servers. This was due to a combination of two factors: lower requirements for average server power under Google Apps, and consolidating GSA servers into a smaller subset of specialized locations that had the best PUEs.
3. These results only covered energy consumption for servers and the associated cooling—not energy consumption for client devices (e.g., laptops). The estimated direct + indirect energy consumption of GSA's 18,300 laptops (~3,600,000 kWh) did not significantly change during the migration. Including this amount in the comparison, we would estimate a total client + server energy savings of 39%.[14]

Conclusions

This whitepaper suggests that migrating to the cloud can produce estimated energy savings of 68–87% for typical companies. Replicating these savings across the entire economy would have a substantial impact. According to a recent study by the Carbon Disclosure Project, by migrating to cloud computing, large U.S. companies could achieve annual energy savings of $12.3 billion and carbon reductions of 85.7 million metric tonnes by 2020—equivalent to the annual emissions of over 16.8 million passenger vehicles.[15] This suggests that cloud computing can in fact be seen as part of the solution towards a more energy efficient future.

Appendix: Notes on assumptions and methodology

This section provides justification for the numbers shown in the first table of the document.

Typical energy consumption today

We calculated the low and high range for estimates in this table by considering two types of businesses. The low estimates are appropriate for a "data-light" business (e.g., largely clerical) that has relatively low-power computers and servers. The high estimates are appropriate for a data-intensive business (e.g., an engineering firm) with a greater number of higher powered computers and servers.

For client devices (e.g., desktops, laptops, etc.), we assumed 1 laptop and 0.2 desktops per user in the low estimate, with an annual direct energy consumption of 60 kWh for the laptop and 160 kWh for the desktop. These energy consumption numbers are appropriate for a low-end computer or mid-range Energy Star-qualified device.[16] In the high estimate, we assumed 1 laptop and 0.8 desktops per user, with an annual direct energy consumption of 160 kWh for the laptop and 400 kWh for the desktop. These energy consumption figures are appropriate for a typical higher-end 60 watt laptop and a 150 watt desktop that are on for 2,600 hours per year. We multiplied both high and low estimates by a further factor of 1.5 to account for the additional air-conditioning needed to remove the devices' heat.

For servers and server cooling, we assumed an average server power of 200 watts, one server per 50 employees, and a PUE of 2.0 in the low estimate, while assuming an average server power of 500 watts, one server per 10 employees, and a PUE of 1.5 in the high estimate. We assumed 8,766 operating hours per year in both.

Size of potential customer energy savings in migrating to Google Apps

The low-high estimates in this section are based on the same data-light and data-intensive company archetypes defined in the previous section.

For server energy consumption after implementing Google Apps, we assumed a 90% reduction in number of servers in the low estimate. This large reduction reflects the fact that the work in the "data-light" business is heavily weighted towards the basic office applications that Google Apps can replace. In the high estimate, we assumed a 70% reduction in number of servers for the data-intensive business, reflecting the fact that this workplace has many power users who rely on custom applications that still need on-site server support after the Apps migration. As above, we assumed a PUE of 2.0 for the data-light business and a PUE of 1.5 for the data-intensive business.

While not included in our analysis, for the estimated savings in client devices referenced on page 3, we assumed in the low estimate that 80% of the laptops and 80% of the desktops in the data-light business could be replaced by Chromebooks, reflecting the relatively routine use of computing resources that make up employees' work in this kind of company. We assumed in the high estimate that only 25% of the data-intensive laptops and 5% of the data-intensive desktops could be replaced by Chromebooks. This reflects an underlying assumption that proprietary, non-enterprise software plays a large role in the work of employees at the data-intensive company. In both the low and high cases, we calculated the energy savings from the replacement using the laptop and desktop energy consumption levels described above, and a Chromebook annual energy consumption of 30 kWh/yr. The Chromebook consumption is based on 11 watt consumption when awake, 0.5 watt consumption when asleep, and 20% fewer "on hours" per year than the desktop or laptop it replaces. The very fast Chromebook start-up and shut-down times encourage users to turn off the devices more frequently, resulting in fewer "on hours."

Per-user energy required for Google to operate Google Apps

We estimated the energy required to support one incremental Google Apps user for a year by summing the energy required to support an average user in each of our three most popular applications: Gmail, Calendar, and Docs (which includes spreadsheets, documents, presentations, etc.) and then multiplying by a small scale-up factor to account for other applications provided by Google Apps.

For each of the three applications, we estimated the energy requirement per user by taking the total number of cores and disk space devoted to the current users of that service (including redundancy), multiplying by the relevant annual energy consumption (kWh per year per core or kWh per year per GB storage), multiplying by Google's trailing 12-month PUE (i.e., 1.13 at the time of publication), and then dividing by the number of 7-day active users.

We then added a 10% energy premium per user to account for network energy consumption, which is approximately the value advocated by Baliga and collaborators[17] for applications like Google Enterprise that have low screen-refresh rates.

This approach leads to an estimate of ~2 kWh/yr to serve the average Google Apps customer. Heavier users will require more energy to support, and lighter users will require less. We have adopted the range 1–5 kWh/yr as our energy estimate to accommodate the range of behaviors seen among typical customers.

1. From Carbon Disclosure Project and Verdantix, **Cloud Computing – The IT Solution for the 21st Century**, 2011.
2. The white paper was released in the Official Google Blog post, **Gmail: It's cooler in the cloud**, 2011.
3. More information is available on the Google Enterprise site at **www.google.com/enterprise/**.
4. This is the reduction in server energy use specific to email and collaboration services after migrating to Google Apps. Customers may continue to maintain servers onsite for tasks that cannot be outsourced to Google Apps (e.g., specialized design software), which we have not included in our analysis.
5. From Accenture and WSP, **Cloud Computing and Sustainability: the Environmental Benefits of Moving to the Cloud**, 2011.
6. Further discussion of sources of inefficiency in typical server deployments can be found in the white paper, **Google's Green Computing: Efficiency at Scale**, 2011.
7. Trailing 12-month average power usage effectiveness (PUE). Google's PUE was 1.12 in the most recent quarter (Q1 2012). See **www.google.com/about/datacenters/inside/efficiency/power-usage.html** for details.
8. Additional information on the performance of Google datacenters can be found at **www.google.com/about/datacenters/inside/efficiency/power-usage.html**.
9. From Jayant Baliga et al, **Green Cloud Computing: Balancing Energy in Processing, Storage, and Transport**, 2011. Proceedings of the IEEE, Vol 99, p. 149.
10. This includes the incremental energy consumption from Google data centers and network traffic needed to support Google Apps.
11. Power Usage Effectiveness. A measurement of how much indirect energy (e.g., air conditioning) is needed to support a server's direct energy consumption. A PUE of 2.5 means that 1.5W of indirect power is needed for each 1W of server power, while a PUE of 1.7 means that 0.7W of indirect power is needed for each 1W of server power.
12. This assumes a PUE of 1.7 for GSA's two largest data centers and a PUE of 2.5 for smaller, less optimized locations. These numbers are consistent with GSA's estimates of their data centers at two locations (i.e., one large, one small) and with IBM's estimates of efficiencies for strategic (i.e., high-end) and basic data centers in their 2012 report, **Data Center Operational Efficiency Best Practices**.
13. This includes the incremental energy consumption in Google data centers and network energy that is needed to support Google Apps.
14. This is the weighted average of 87% savings in server energy and ~0% savings in client energy.
15. From Carbon Disclosure Project and Verdantix, **Cloud Computing – The IT Solution for the 21st Century**, 2011.
16. From the **Energy Star program requirements for computers**, Version 5.0.
17. From Jayant Baliga et al, **Green Cloud Computing: Balancing Energy in Processing, Storage, and Transport**, 2011. Proceedings of the IEEE, Vol 99, p. 149.

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